

# Regional Supply of Hydrogen

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National Renewable Energy Laboratory  
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DOE Hydrogen and Fuel Cells Program  
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID # SA063

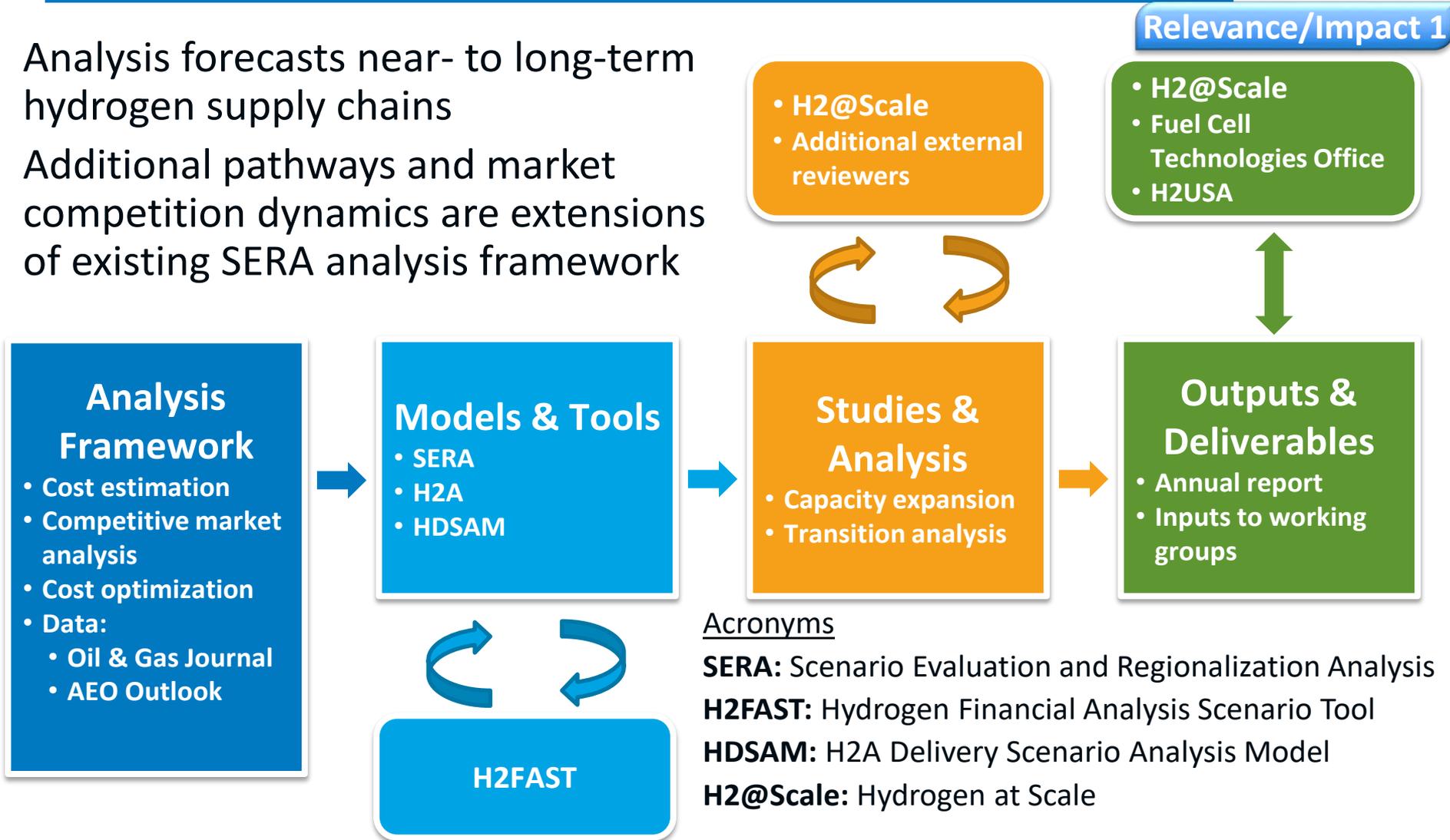
# Overview

Timeline	Barriers
<p>Start: October, 2016</p> <p>End: September, 2018*</p> <p>* Annual direction determined by DOE</p>	<p><b>4.2 Technical Approach:</b> Infrastructure Analysis</p> <p><b>4.5 A. Future Market Behavior:</b> Scenarios to understand vehicle-fuel interactions</p> <p><b>4.5 E. Unplanned Studies and Analysis</b> Response to H2USA public-private partnership and infrastructure deployment goals</p>
Budget	Partners
<p>FY18 Planned DOE Funding: \$55K</p> <p>Funds Received to Date: \$180K</p>	<p><b>External References</b></p> <ul style="list-style-type: none"><li>• Oil &amp; Gas Journal</li><li>• H2A</li><li>• HDSAM</li></ul> <p><b>Planned Reviewers</b></p> <ul style="list-style-type: none"><li>• H2USA working group members</li><li>• California Energy Commission</li><li>• Academic experts</li><li>• Fuel Pathways and Integration Tech Team (FPITT)</li></ul>

# Regional Supply analysis enables forecast of competitive retail price and availability of fuel

Analysis forecasts near- to long-term hydrogen supply chains

Additional pathways and market competition dynamics are extensions of existing SERA analysis framework



## Acronyms

**SERA:** Scenario Evaluation and Regionalization Analysis

**H2FAST:** Hydrogen Financial Analysis Scenario Tool

**HDSAM:** H2A Delivery Scenario Analysis Model

**H2@Scale:** Hydrogen at Scale

**H2@Scale synergy:** This light duty vehicle market analysis project helped develop the same modeling tools and analysis framework used by H2@Scale

# Analysis of production expansion dynamics forecasts infrastructure equipment and finances

Relevance/Impact 2

## Objectives

- Evaluate existing hydrogen production capacity and hypothetical excess capacity
- Forecast production capacity expansion requirements for growing FCEV market demand
- Simulate regional supply chain network dynamics
- Incorporate market competition considerations



## Impacts on FCTO barriers during reporting period

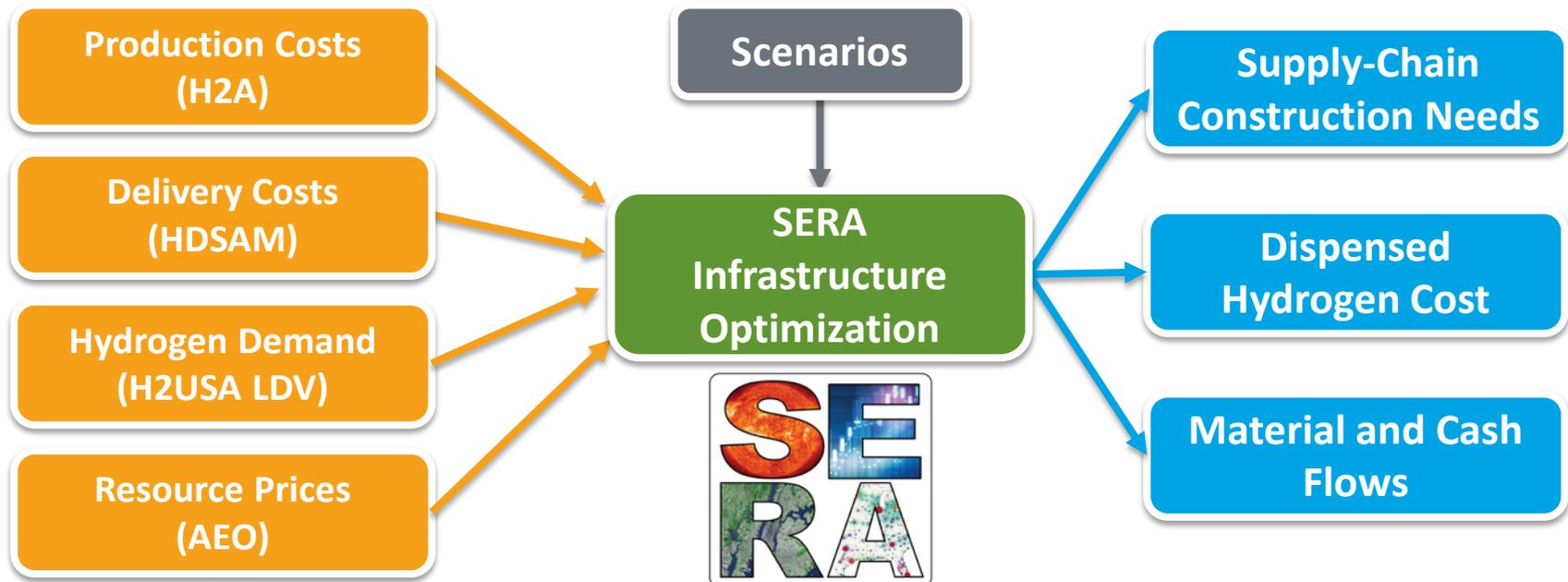
- Enhanced analysis of future hydrogen production and retail fueling market behavior (Barrier A)
- Provide timely analytical capabilities to FCTO (Barrier E)

**Forecasting incorporates updated and comprehensive supply chain pathways technology competition**

# Supply-Chain Analysis Using the *SERA* Model

## Approach 1

- The *Scenario Evaluation and Regionalization Analysis (SERA)* modeling framework develops optimized hydrogen supply networks in response to FCEV hydrogen demands
- Accounts for the geography of energy resource availability, extraction and conversion costs, transmission and distribution costs, and retail station network costs
- Competes multiple supply-chain technologies to identify least-cost supply options both temporally and spatially



# Demand: Light Duty FCEV Hydrogen Demand Based on H2USA Analysis

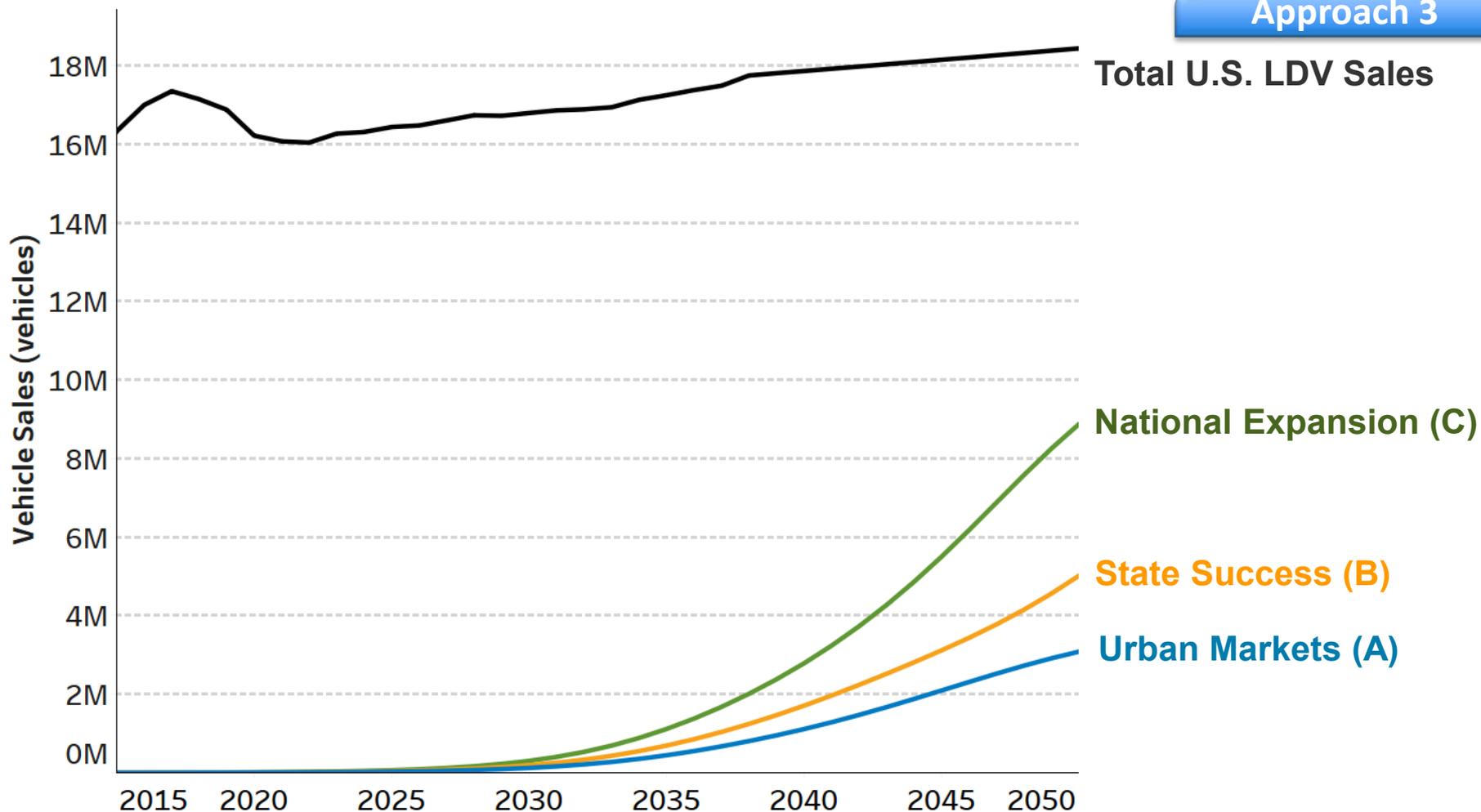
## Approach 2

Market Influence	Urban Markets	State Success	National Expansion
Dominant market drivers	Support at local and municipal levels combined with strong early adopter demand	ZEV mandate and other state market support mechanisms	Combination of strong local, state, and national market support mechanisms
Coordination and planning	Investments focused on most promising metropolitan markets	Strong coordination across ZEV mandate states	Strong coordination and planning across all regions
Consumer adoption	High concentrations of early adopters guide market development	FCEV adoption primarily driven by ZEV mandate	Adoption moves quickly from concentrated early adopters and ZEV mandate states to broad megaregion markets
HRS network expansion	Gradual expansion from promising urban markets to nearby cities	Focus on ZEV mandate states, with gradual expansion into additional markets	Strong stakeholder planning and coordination reduces investment risks, allowing rapid network expansion
FCEV sales per year (millions) and total urban area market share (%) in 2050			
United States	3.1 M (23%)	5.0 M (35%)	8.9 M (59%)
California (CA)	1.0 M (49%)	1.3 M (64%)	1.7 M (84%)
Other ZEV States (ZEV)	0.9 M (26%)	1.9 M (56%)	1.9 M (57%)
Rest of Country (ROC)	1.2 M (10%)	1.9 M (14%)	5.3 M (41%)

**Light-duty fuel-cell vehicle hydrogen demand growth based on H2USA National Scenarios Report**

# *Demand:* National Light-Duty FCEV Sales For Each H2USA Scenario

Approach 3



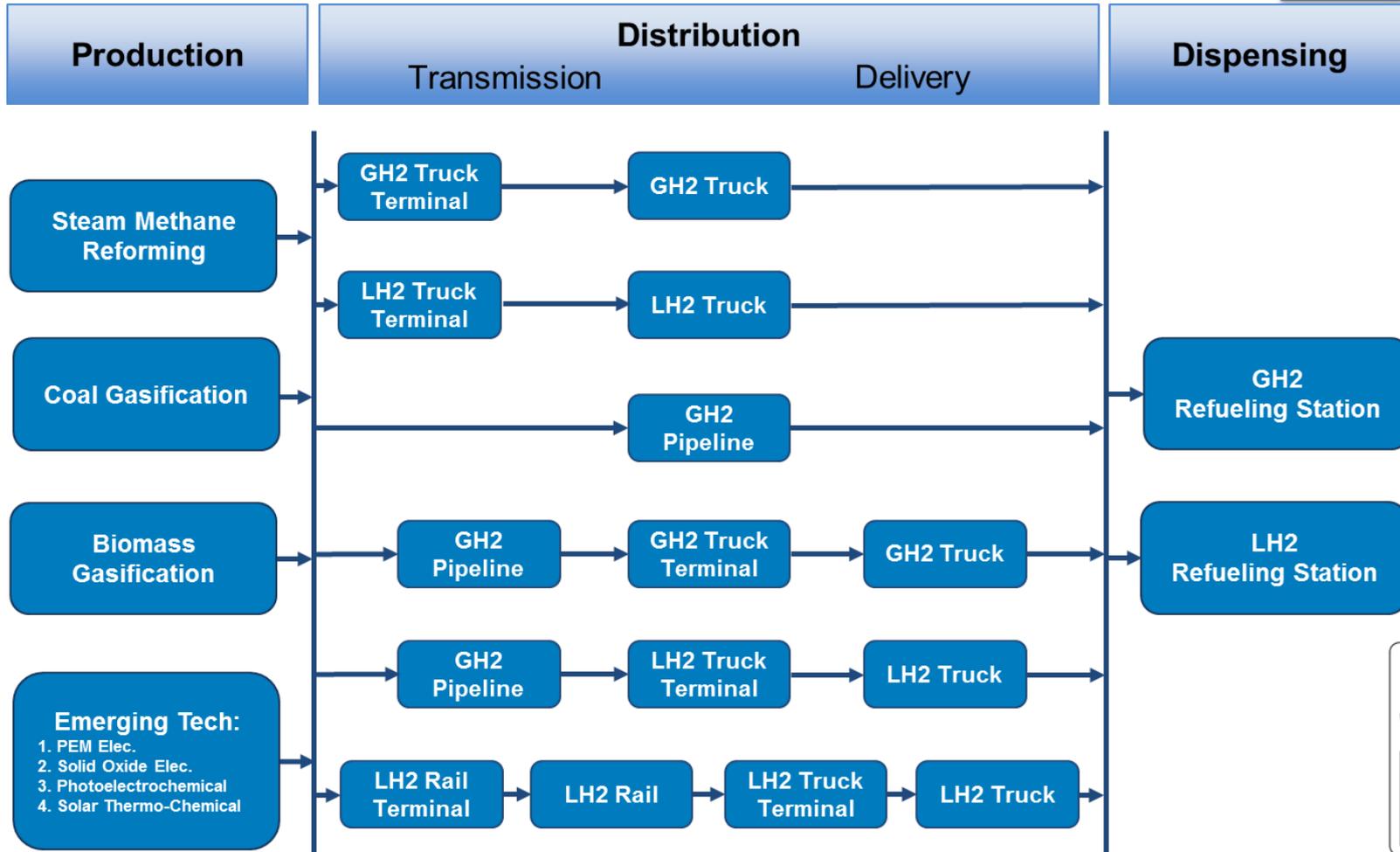
**State Success (B) scenario is used as base case scenario**

National Hydrogen Scenarios Report:

[http://h2usa.org/sites/default/files/H2USA\\_LRWG\\_NationalScenarios2017.pdf](http://h2usa.org/sites/default/files/H2USA_LRWG_NationalScenarios2017.pdf)

# Supply: Production (H2A) and Delivery (HDSAM) Technologies Integrated into SERA for Competitive Analysis

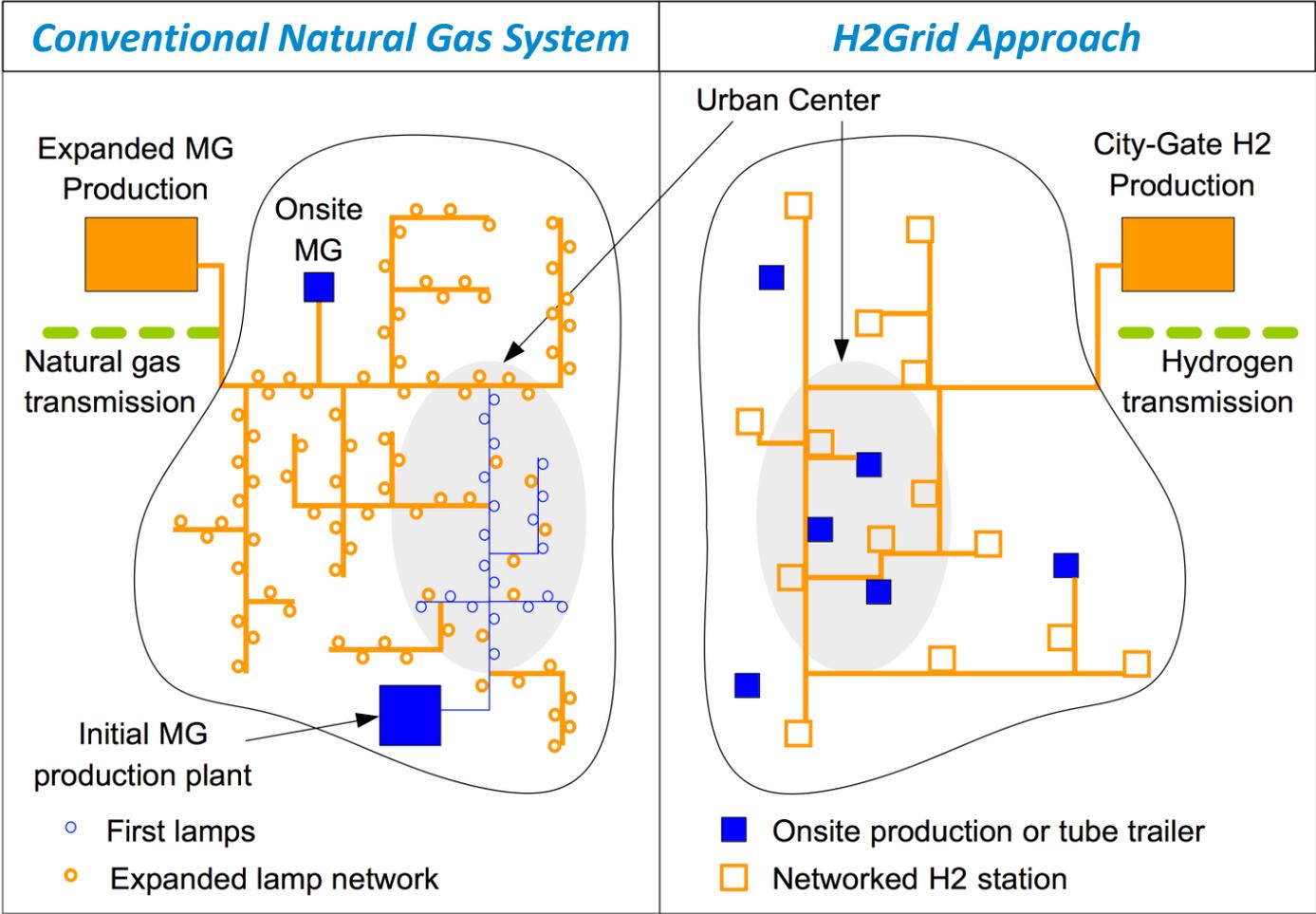
Approach 4



Pathways are competed with geographic consideration of resources availability, prices, and outlook of hydrogen demand growth

# Supply: Proposing a New, Hydrogen Delivery Pathway (*H2Grid*) To Compete In SERA

Approach 5



Similar Staged Progression

- Local units
- Distribution network
- Transmission from remote production facilities

**Historic precedence:** town-gas infrastructure started with local pipeline delivery, followed by external city supply of natural gas delivered above usage pressure

# Supply: The *H2Grid* Approach and Benefits

## Approach 6

### **H2Grid Approach:**

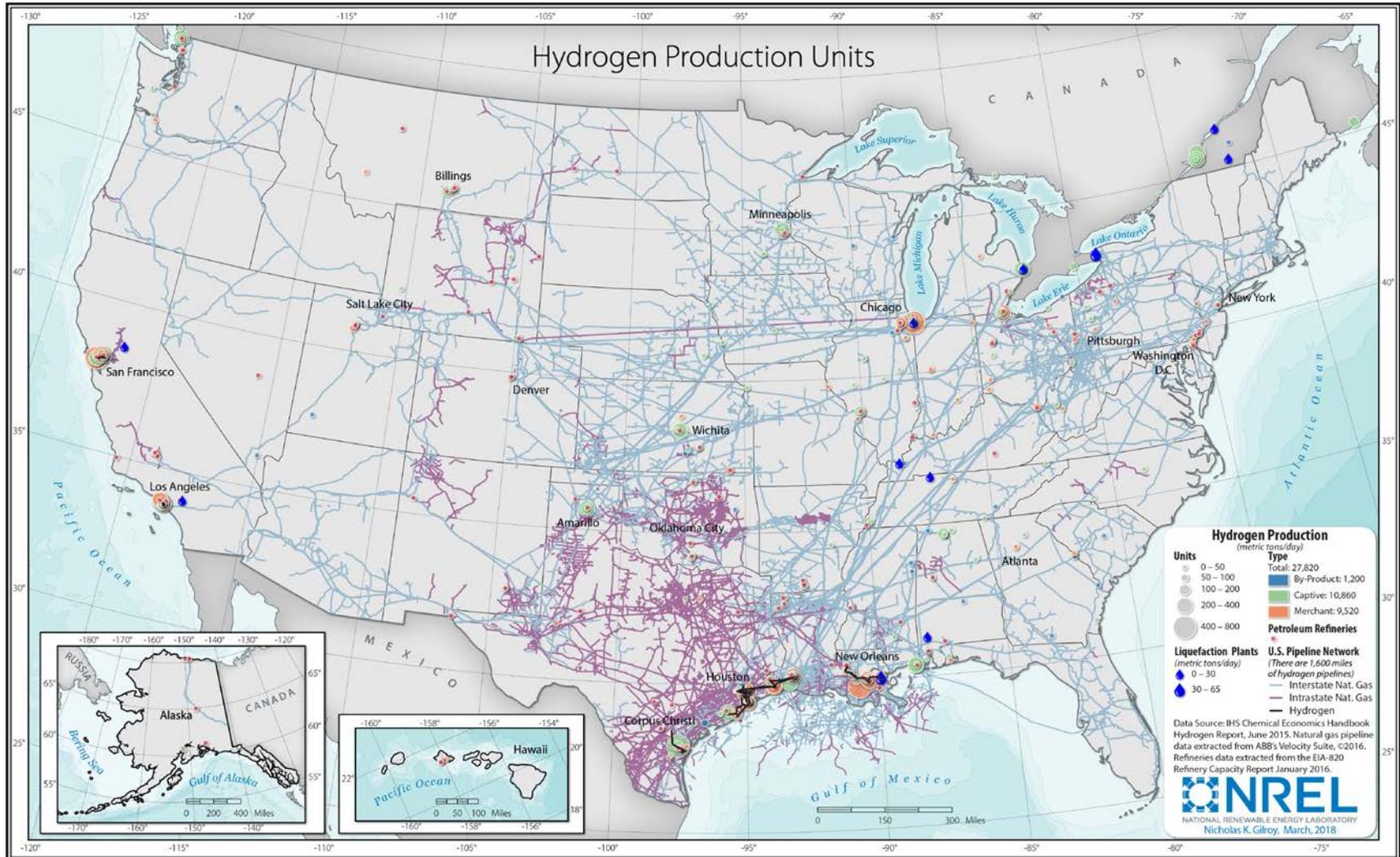
- Production, storage, and compression in semi-central
- High pressure (1,000 bar) local delivery pipeline
- Interconnected grid of hydrogen pipelines and refueling stations
- Cooling and dispensing at forecourt

### **H2Grid Benefits:**

- **Enhanced retail station adoption:**
  - Lower upfront station cost
  - Reduced station operating complexity
- **Smaller retail footprint:**
  - No on-site storage or compressors (reduced set-back distances)
- **Cheaper compression:**
  - Large, central compressor is much cheaper than many smaller compressors
  - Lower operating cost as larger compressors are more efficient
  - Improved compressor oversight and reliability
- **Improved network reliability:**
  - Interconnected grid and production sites provide mutual redundancy
  - Back-to-back fueling improved due to high-pressure storage in pipes and at production site
  - No reliance on discrete delivery units, traffic issues, offload limits
- **Improved safety**
  - No on-road exposure, truck filling, or off-loading

# Existing Hydrogen Production Capacity Compiled and Integrated into SERA Model

## Accomplishments 1

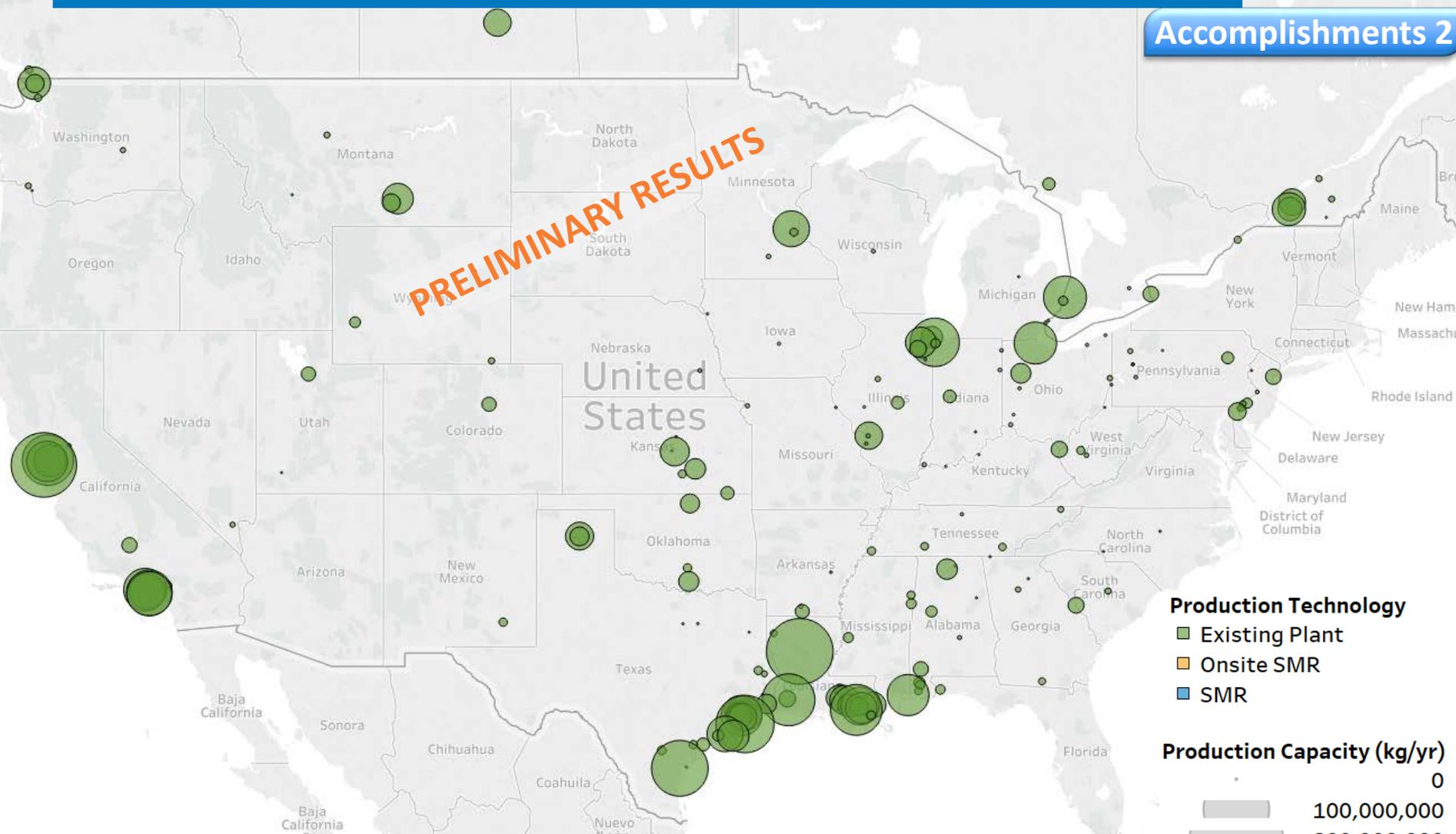


Existing hydrogen production plants were incorporated into SERA

# SERA Results: Production Capacity Expansion by 2018 (Scenario B: State Success)

Accomplishments 2

PRELIMINARY RESULTS



Few new production plants are built by 2018 due to low, localized demand and available supply from existing plants

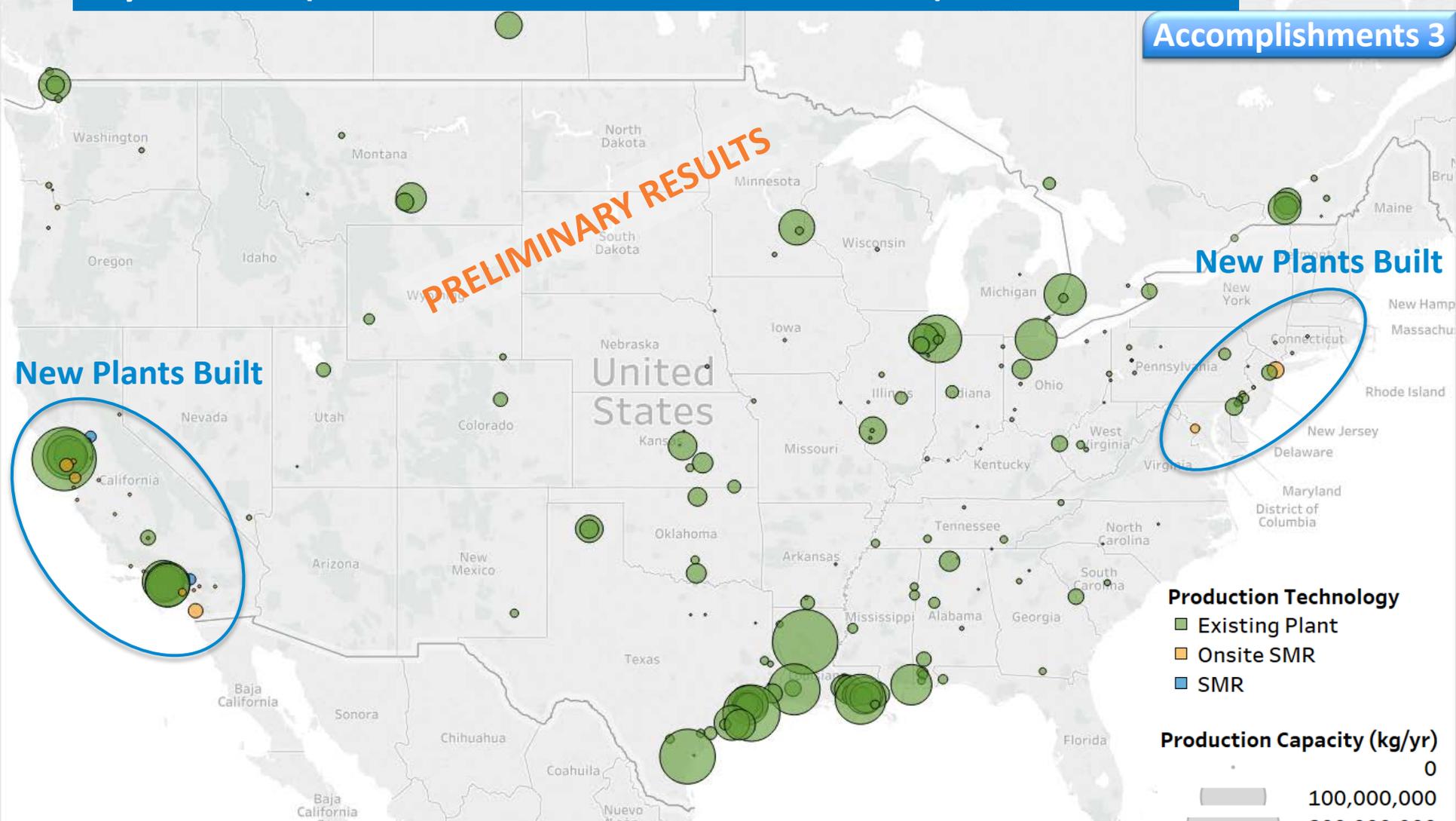
# SERA Results: Production Capacity Expansion by 2021 (Scenario B: State Success)

Accomplishments 3

PRELIMINARY RESULTS

New Plants Built

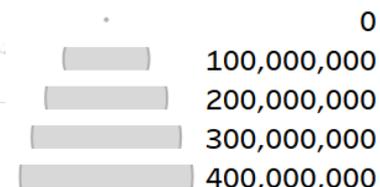
New Plants Built



## Production Technology

- Existing Plant
- Onsite SMR
- SMR

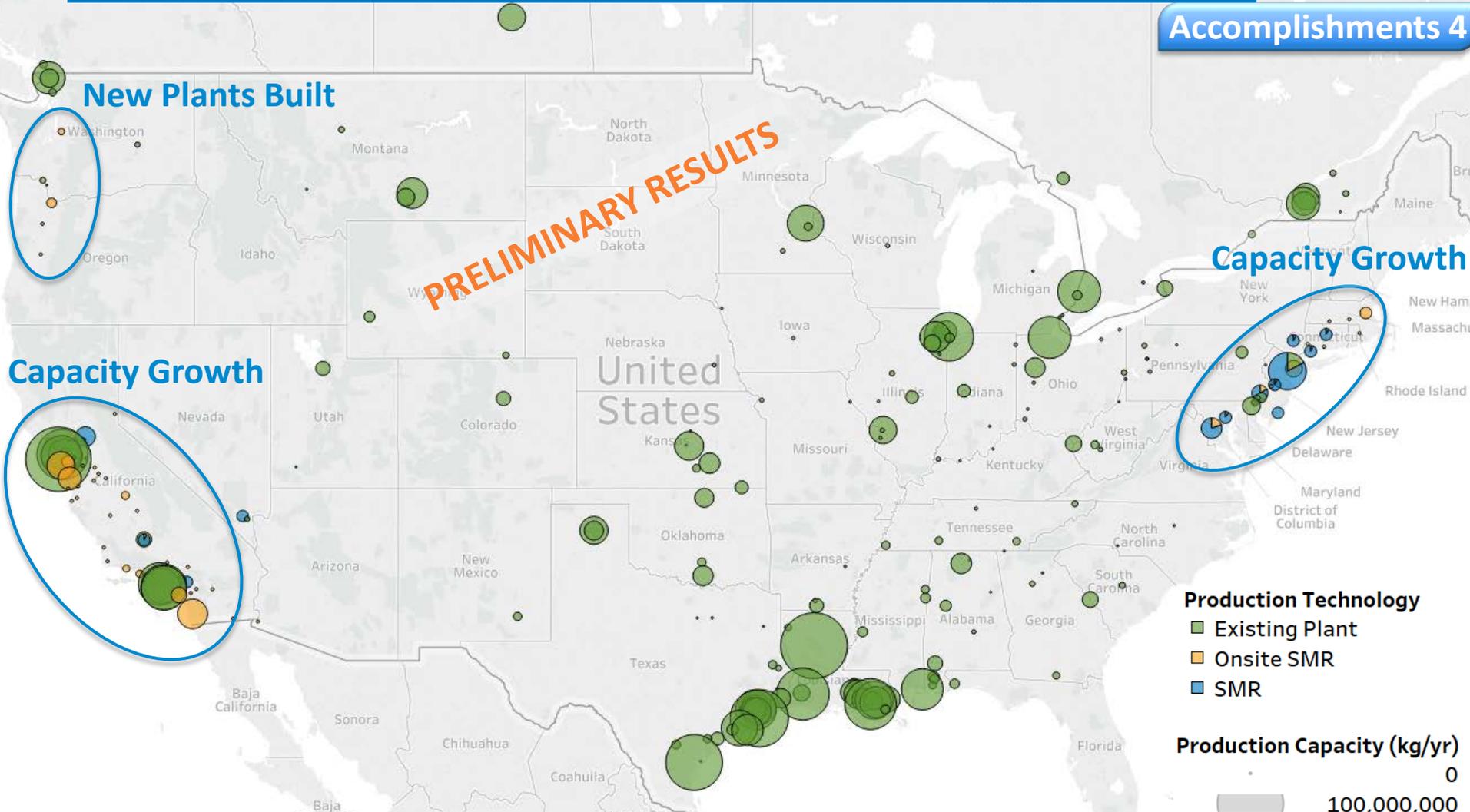
## Production Capacity (kg/yr)



By 2021, production capacity expansion needs are estimated to be in New York, Washington DC, Los Angeles, and Bay Area

# SERA Results: Production Capacity Expansion by 2026 (Scenario B: State Success)

Accomplishments 4

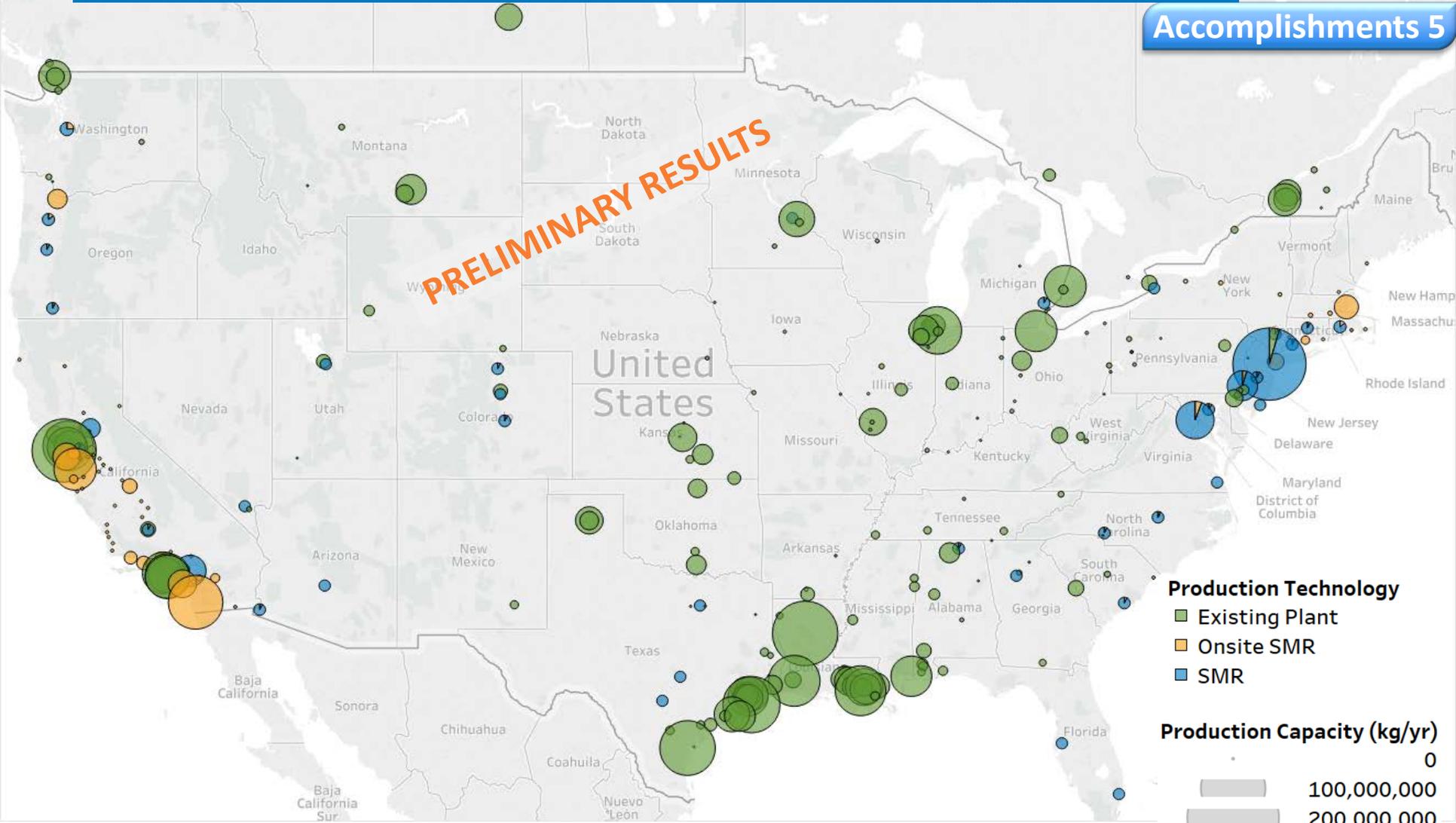


By 2026, second tier of expansion is expected in Seattle, Boston. Capacity growth in CA and North-East continues

# SERA Results: Production Capacity Expansion by 2031 (Scenario B: State Success)

Accomplishments 5

PRELIMINARY RESULTS

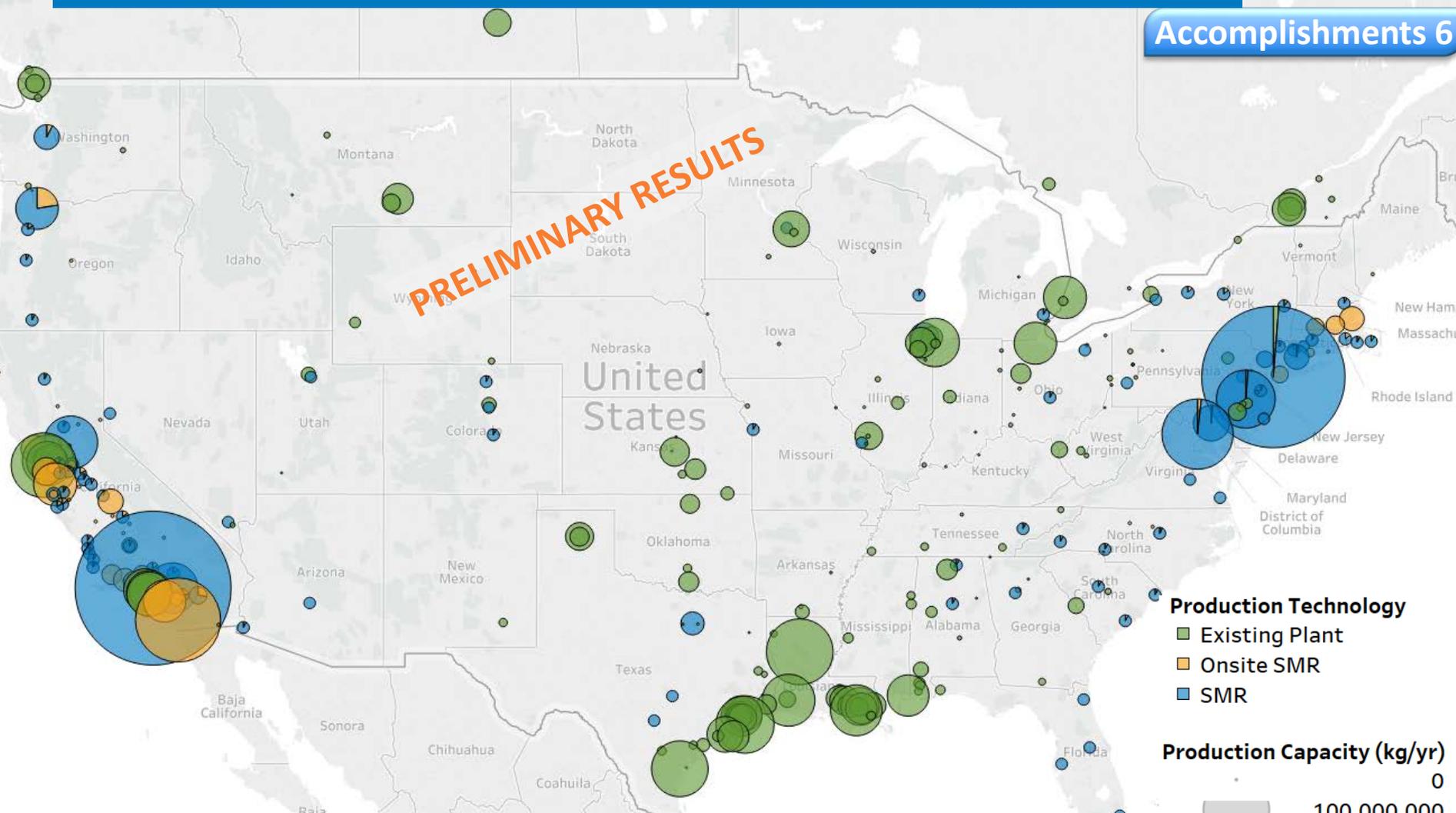


By 2031, inland market growth ramps up in urban areas

# SERA Results: Production Capacity Expansion by 2036 (Scenario B: State Success)

Accomplishments 6

PRELIMINARY RESULTS

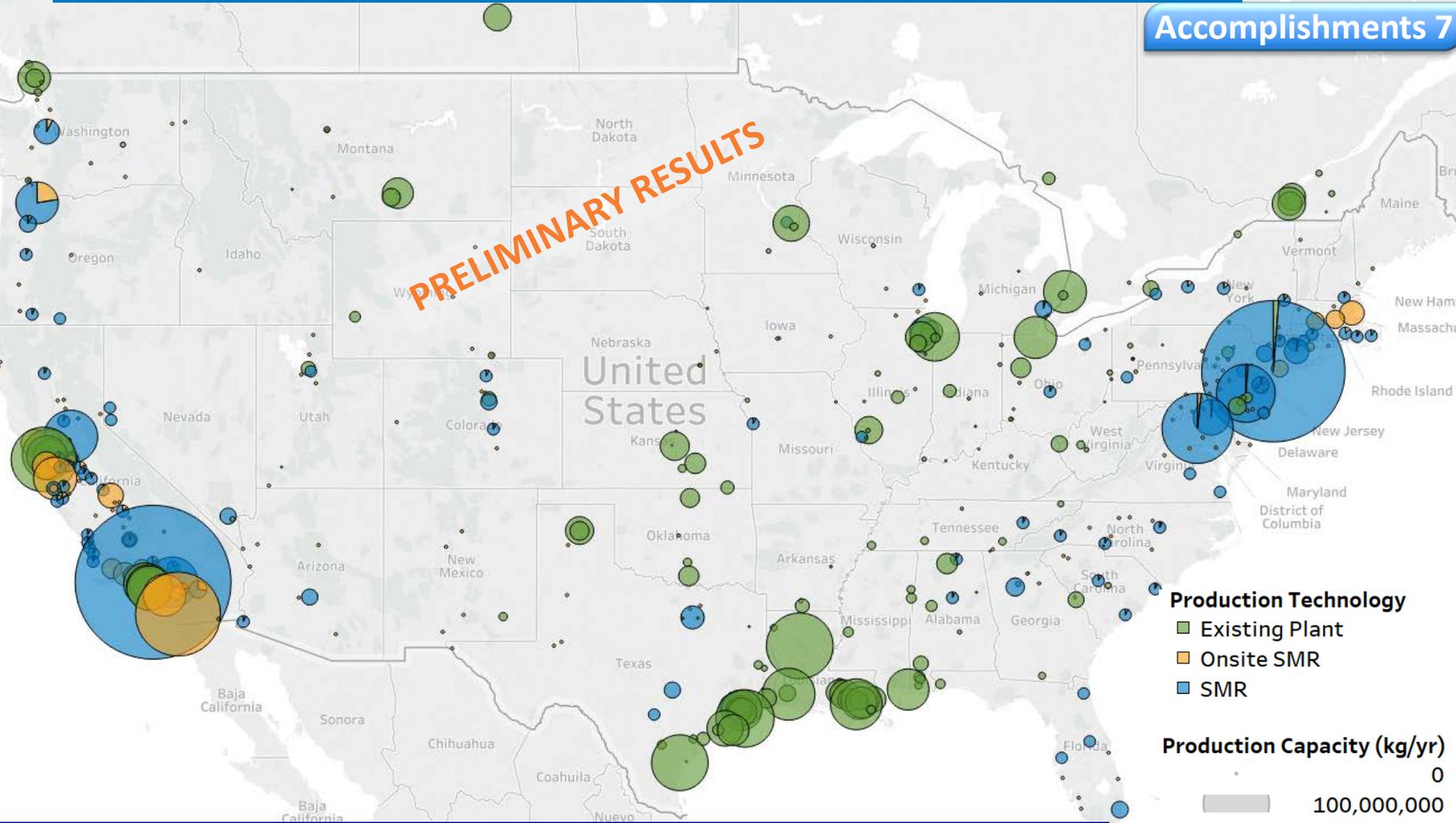


By 2036, hydrogen demand continues to ramp up, large new central SMRs are built in California and Northeast

# SERA Results: Production Capacity Expansion by 2040 (Scenario B: State Success)

Accomplishments 7

PRELIMINARY RESULTS

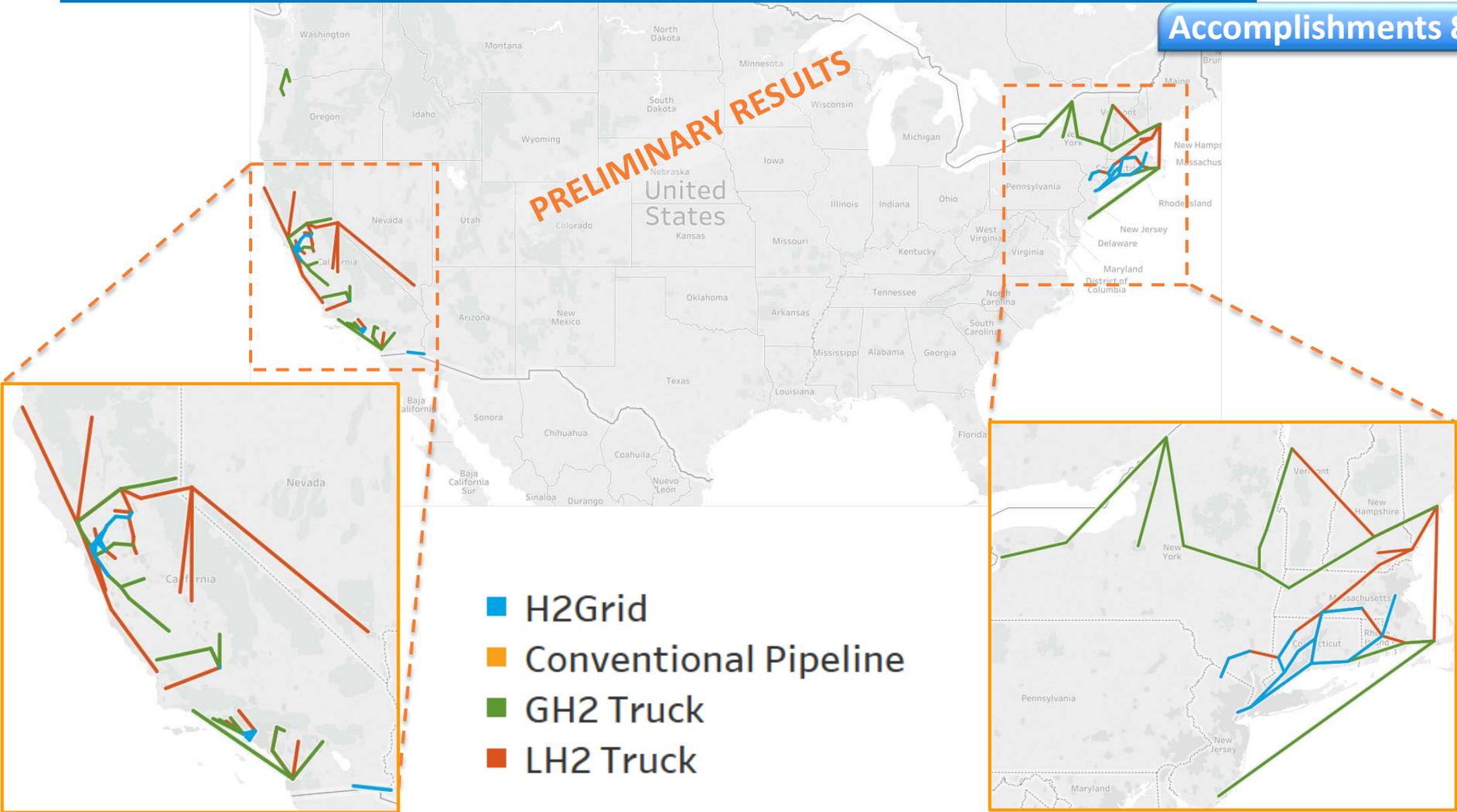


In 2040, smaller urban areas begin to develop hydrogen demand and require small, local production facilities

# SERA Results: Incremental Transmission by 2040 (Scenario B: State Success)

Accomplishments 8

PRELIMINARY RESULTS

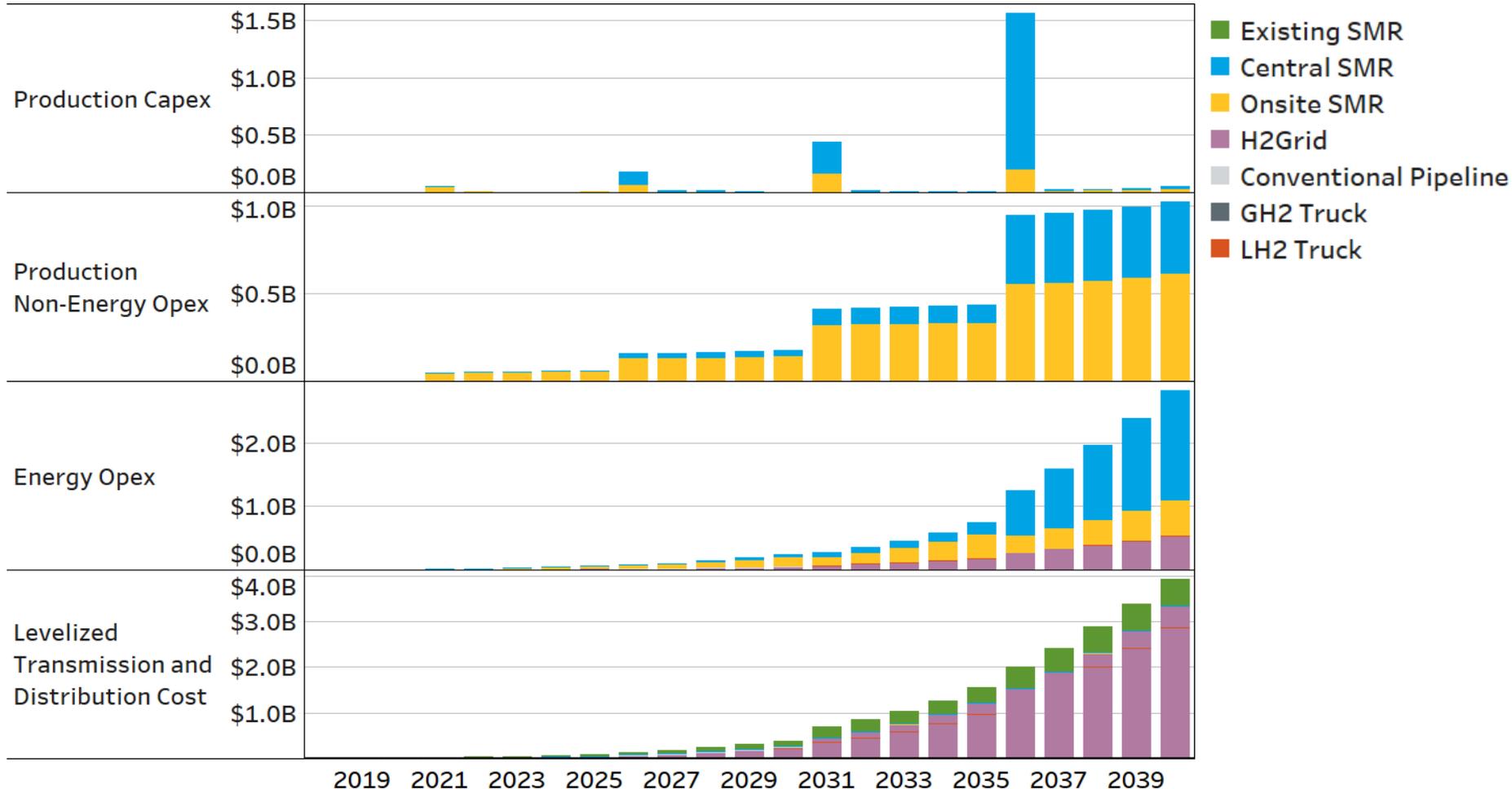


New long distance transmission is sparse due to use of local existing hydrogen supply and high transmission costs

# SERA Results: Required Infrastructure Investment By Supply-Chain Segment

Accomplishments 9

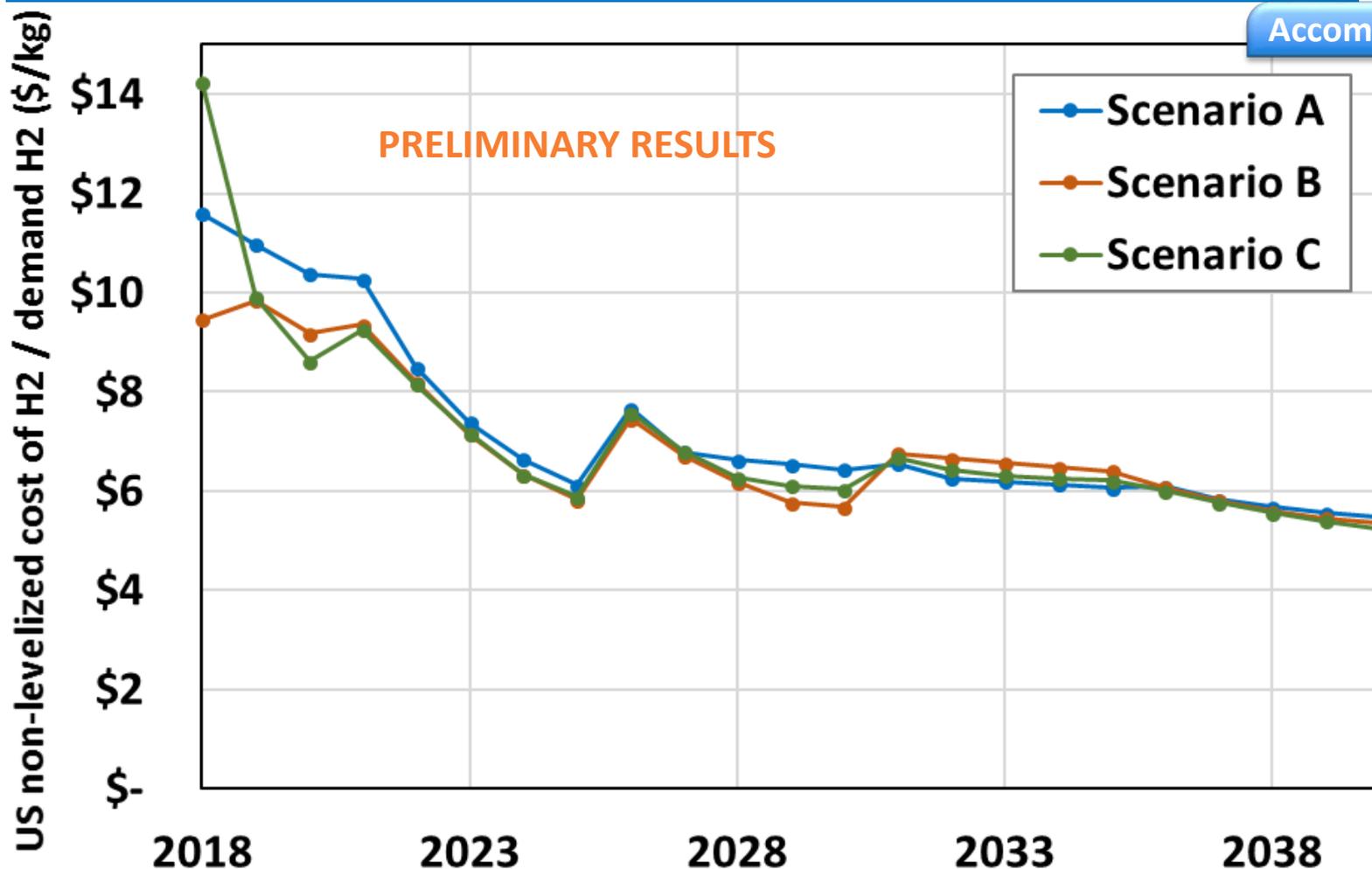
Infrastructure investment precedes demand growth trajectory. Capital investment periodicity of 5 years is an artifact of modelling 5-year outlook for investment horizon.



Above is projected distribution of capital expenditure, maintenance (non-energy OPEX), and transmission. Note that transmission expenditures have been levelized for modelling purposes.

# *SERA Results:* Hydrogen Profited Cost For Each Light-Duty FCEV Demand Scenario

Accomplishments 10

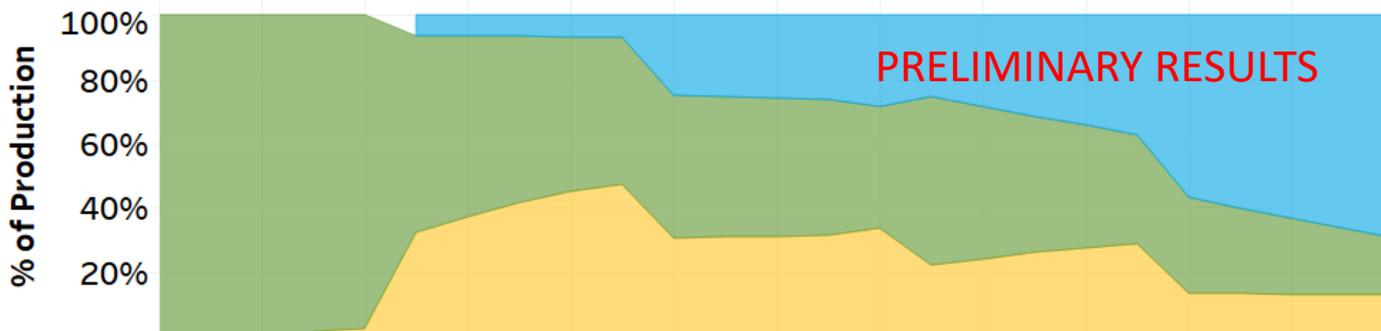


- Spikes in H2 cost are artifact of non-levelized cost used in algorithm along with 5-year capital project outlook criteria.
- Scenario C has slightly lower cost due to economies of scale. Scenario C also has more rural low-density markets, which produce upward pressure on H2 price.

# SERA Results: State Success (B) Production, Transmission, and Dispensing Technologies

Accomplishments 11

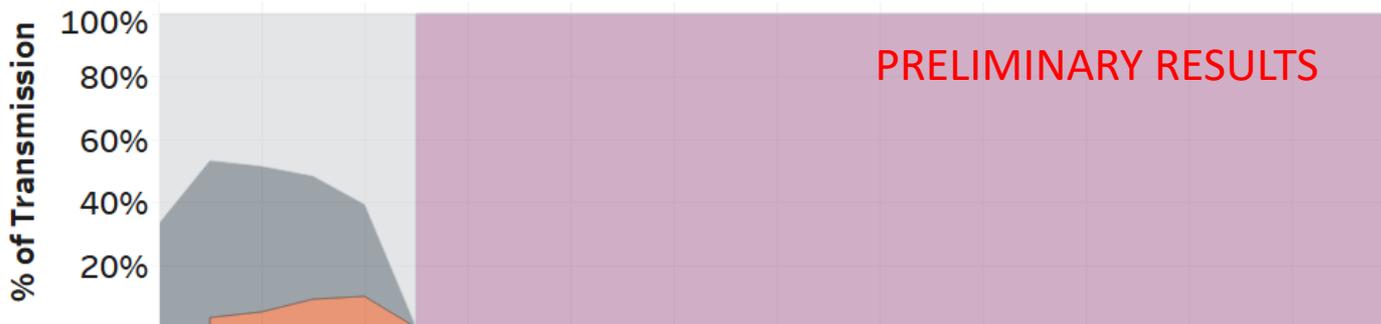
## Production Mix



- Central SMR
- Existing Plant
- Onsite SMR

SMR dominates through 2040

## Long-Distance Transmission Mix

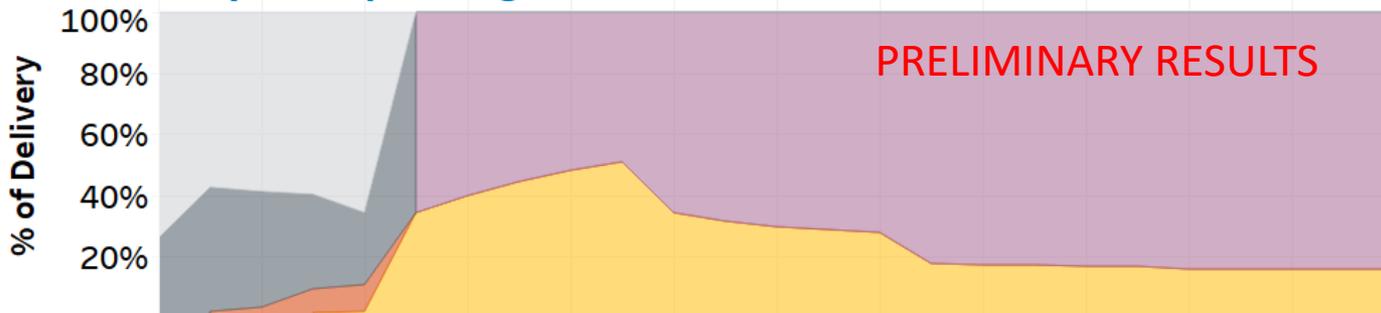


- Conventional Pipeline
- H2Grid
- GH2 Truck
- LH2 Truck

Pipeline *transmission* has highest economic prevalence

Early *delivery* trucks are replaced by pipeline and onsite SMR production

## Delivery & Dispensing Mix



2018 2020 2022 2024 2026 2028 2030 2032 2034 2036 2038

# SERA Results: H2Grid Build-Out In Los Angeles in 2038

Accomplishments 12

## PRELIMINARY RESULTS

Characteristics for year	2038
Number of pipeline segments	669
Cumulative length (miles)	1,179.78
Average segment length (miles/segment)	1.76
Delivery throughput (kg/d)	1,251,557
Distribution cost (\$/kg)	\$ 0.51

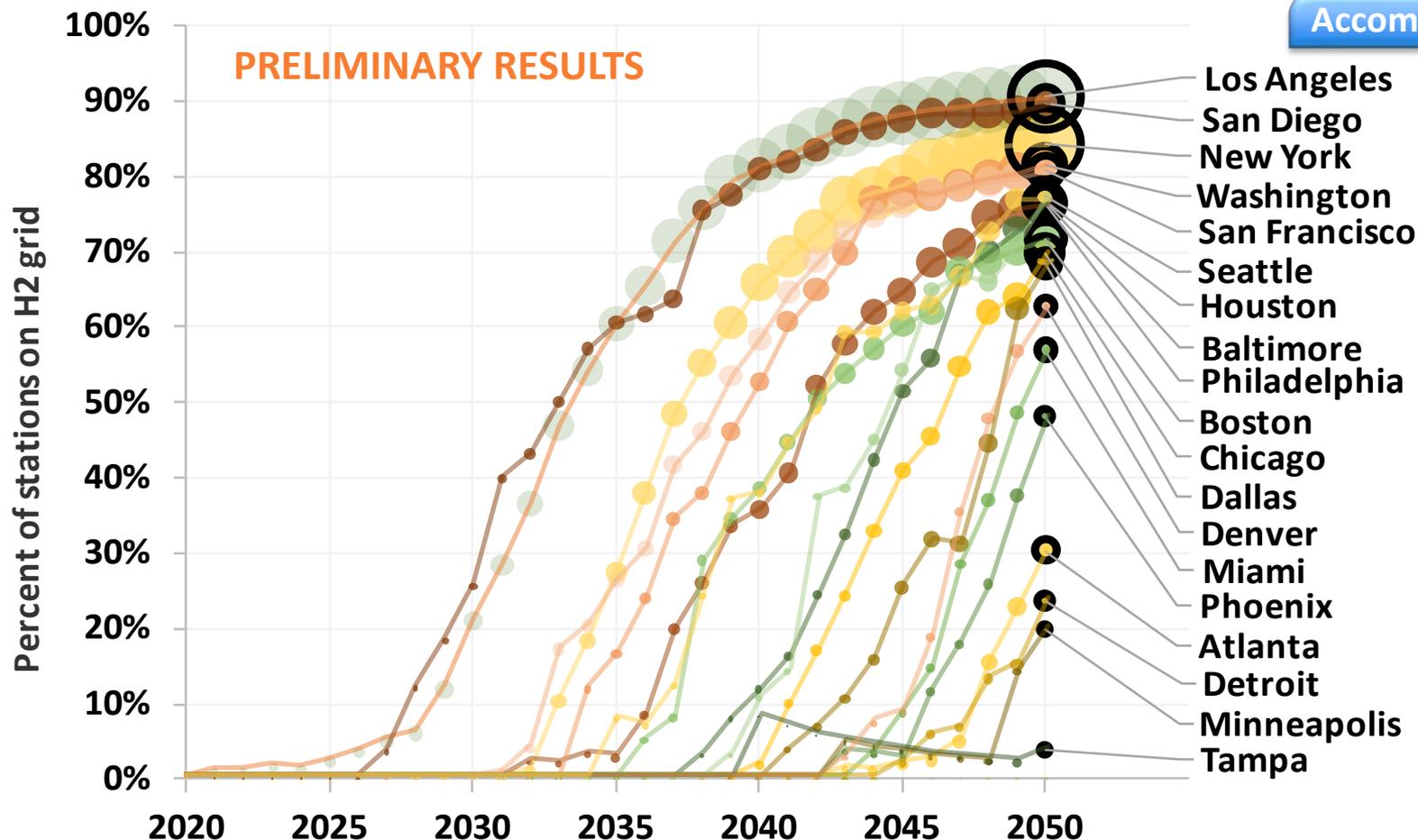
Los Angeles  
Year = 2038

- Station size = 60 - 710 kg/d
- Station size = 710 - 1270 kg/d
- Station size = 1270 - 1900 kg/d
- Station size = 1900 - 2810 kg/d
- Station size = 2810 - 6830 kg/d

**H2Grid economically outcompetes other supply chain pathways in major urban areas.**

# SERA Results: Percent of Stations Connected to the H2Grid (Scenario B: State Success)

Accomplishments 13



**Major urban areas show significant economic advantage from H2Grid past 2030**

- Hydrogen demand grows significantly
- Distance between refueling stations shrinks

- **H2@Scale**
  - Modelling framework was developed for this project and H2@Scale. Demand scenarios are also shared between these projects.
- **Argonne National Laboratory**
  - HDSAM and H2A Delivery Components Model
- **California Energy Commission**
  - Leveraging development of SERA analysis capabilities and real-world data updates resulting from support provided to annual CEC/CARB Joint Agency Reports (CEC-funded project)
- **Industry Feedback**
  - CA utility\*
  - Industrial gas company\*

\* Permission has not been obtained to disclose specific contact at this time

### Regional Supply-Chain Analysis

- Use non-levelized costs for transmission/delivery technologies (in progress) (e.g. truck delivery infrastructure may serve market for ~2-3 years, but needs 20 years for business case payback)
- Market competition should be addressed to balance economies of scale and competitive landscape (e.g. How many companies operate in proximity to produce competitive pricing)
- Detailed local station placement SERA model needs to be combined with regional supply-chain optimization SERA model to better understand the interface between regional and local supply-chain optimization
- Available capacity and price from existing hydrogen production plants is uncertain and requires sensitivity analysis to determine its impact on supply-chain build-out

### H2Grid Approach

- H2Grid is overly conservative (\$2M/mile is used as a pipeline cost floor throughout all US cities but should have regional dependence)
- H2Grid deployment offers individual station advantages, and may more realistically lead station placement algorithms

### **Regional Supply-Chain Analysis**

- Produce considerations for infrastructure competitive time window (e.g. is competitive timeframe for truck deliveries sufficient to recover additional investments)
- Perform economic estimate of retail fuel cost with adjusted financial assumptions (Debt / Equity, Interest rates, Tax rates, Return on equity)
- Complete sensitivity analysis around existing hydrogen plant supply availability and selling price
- Incorporate electrolysis at central electricity production facilities (lower cost power than AEO industrial prices)

### **H2Grid Approach**

- Integrate H2Grid build-out algorithm coupled with station placement logic with the regional supply-chain optimization
- Developed more detailed pipeline cost geographic dependency to better account for urban / rural hydrogen grid penetration

Any proposed future work is subject to change based on funding level

# Summary

## Relevance

- Analysis of 2018-2040 timeframe supply chain competitiveness
- Forecast infrastructure extent and investment for 3,000 urban areas

## Approach

- Prime SERA model with existing 28,000 tonnes/day US and Canada production capacity
- Regionally disaggregate three national light duty market demand scenarios
- Perform competitive optimization modelling for all H2A and HDSAM pathways

## Accomplishments and Progress

- Updated and augment all H2A and HDSAM supply chain pathways for consideration
- Introduced H2Grid high-pressure hydrogen delivery pathway
- Hydrogen profited cost was computed at ~\$10/kg in 2018 and \$5.50 in 2040
- Determined likely locations of incremental infrastructure needs between 2018 and 2040
- Quantified investment and operating expenses by technology and supply chain class
- Found large economic driver for H2Grid distribution starting in 2030

## Collaboration

- H2@Scale project team; Argonne National Laboratory; California Energy Commission

## Proposed Future Research

- Improve H2Grid build-out algorithm
- Incorporate projections of non light duty market hydrogen demands (H2@Scale)
- Align cost of capital and financing to current industry reported status
- Develop scenarios using central electrolysis using central power production prices

# Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

**Reviewer Comment:** The team is using the Hydrogen Analysis (H2A) model to project the price. H2A generates a levelized cost and not a price. The price is set by the market. The team should use a levelized cost range in its analysis to compensate.

**Response:** SERA uses capital and operating specifications from H2A cases. It compares technology options to yield lowest cost supply chains. It aggregates total regional expenses and applies a 10% profit margin on capital. As such, it simulates a minimum required selling price which reflects a competitive market. As competing goods are alternative fuel transportation, there is little room for any profit margins larger than ~10%.

# Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

**Reviewer Comment:** The team spent a lot of effort looking for hydrogen production numbers, when this information is available on the Hydrogen Analysis Resource Center (HyARC) website, which is now located on H2Tools.org. Other projects that were doing regional analysis used this data.

**Response:** We have considered HyARC as well. It is a very good public resource. However we have found that the industry report published by IHS Chemical Economics Handbook has the most rigorously collected and regularly updated status information.

# Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

**Reviewer Comment:** The project approach is adequate. However, in the end, production networks will develop based on market conditions, including regulatory requirements, available incentives, and ease of permitting and resource availability, including land for pipelines. These considerations are not yet part of the model.

**Response:** On the supply side, this modeling effort optimizes on economic drivers and projects direction of economic benefit. Hurdles such as regional permitting variations are indeed not considered explicitly but are rolled into overall costs of pipelines reported by past projects. On the demand side, regulatory and market conditions were considered when estimating light-duty FCEV adoption rates and subsequent hydrogen demand.

# Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

**Reviewer Comment:** Setting up an accurate model for distribution is a large and complex task, which was done well in this project. The project shows the stress points geographically as hydrogen needs increase based on current production. One aspect that was not that clear was how “emerging” technologies were simulated at a centralized scale, given the huge extrapolations that would be required.

**Response:** The modeling effort includes technologies which are high technology readiness level (TRL) and have peer-reviewed H2A case-studies. As such, speculation of emerging technologies is not part of this analysis. It would be straightforward to add in potential emerging technologies for other case-studies outside of this project scope.

# Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

**Reviewer Comment:** The first and second objectives have not been met, and no information was presented to cover these topics. Nothing was seen in the presentation about calculating hypothetical excess capacity, which would have been interesting to review. Further, there was no information about how capacity expansion would happen to meet a growing demand for FCEVs.

**Response:** The team looked at multiple means of obtaining excess capacity estimates. This included inquiries to industry, as well as industry monitors. The conclusion of this effort was that surplus capacity is not information in the public realm. It is highly competitively sensitive information and no organization would disclose it. For this analysis, a constant percentage of underutilization was assumed for each plant and that excess supply was available for use. A sensitivity analysis will be completed around this value to understand its importance in hydrogen supply-chain evolution.

# Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

**Reviewer Comment:** The team can give good information. The team seems to be California-specific, with both the California Energy Commission (CEC) and the California Air Resources Board (CARB). Representatives from the Northeast would have been good.

**Response:** Northeast stakeholders have been consulted as NREL participates in H2USA working groups. This analysis does not take special consideration for any state. It uses physical and economic data layers to arrive at regional results. The underlying analysis request is national scenarios. While CA has leadership status in infrastructure roll-out there are no special considerations for trends and economic impacts for the state.

# Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

**Reviewer Comment:** The integration of the Hydrogen Regional Sustainability (HyReS) project, as well as the further opportunities with H2@ Scale, are very appropriate for the continuation of this work.

**Response:** It is indeed the case that HyReS and H2@Scale analysis activities leverage this work and the SERA model. The team cross-informs analysis to the above-mentioned projects.

# Thank You

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[www.nrel.gov](http://www.nrel.gov)

Publication Number

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.



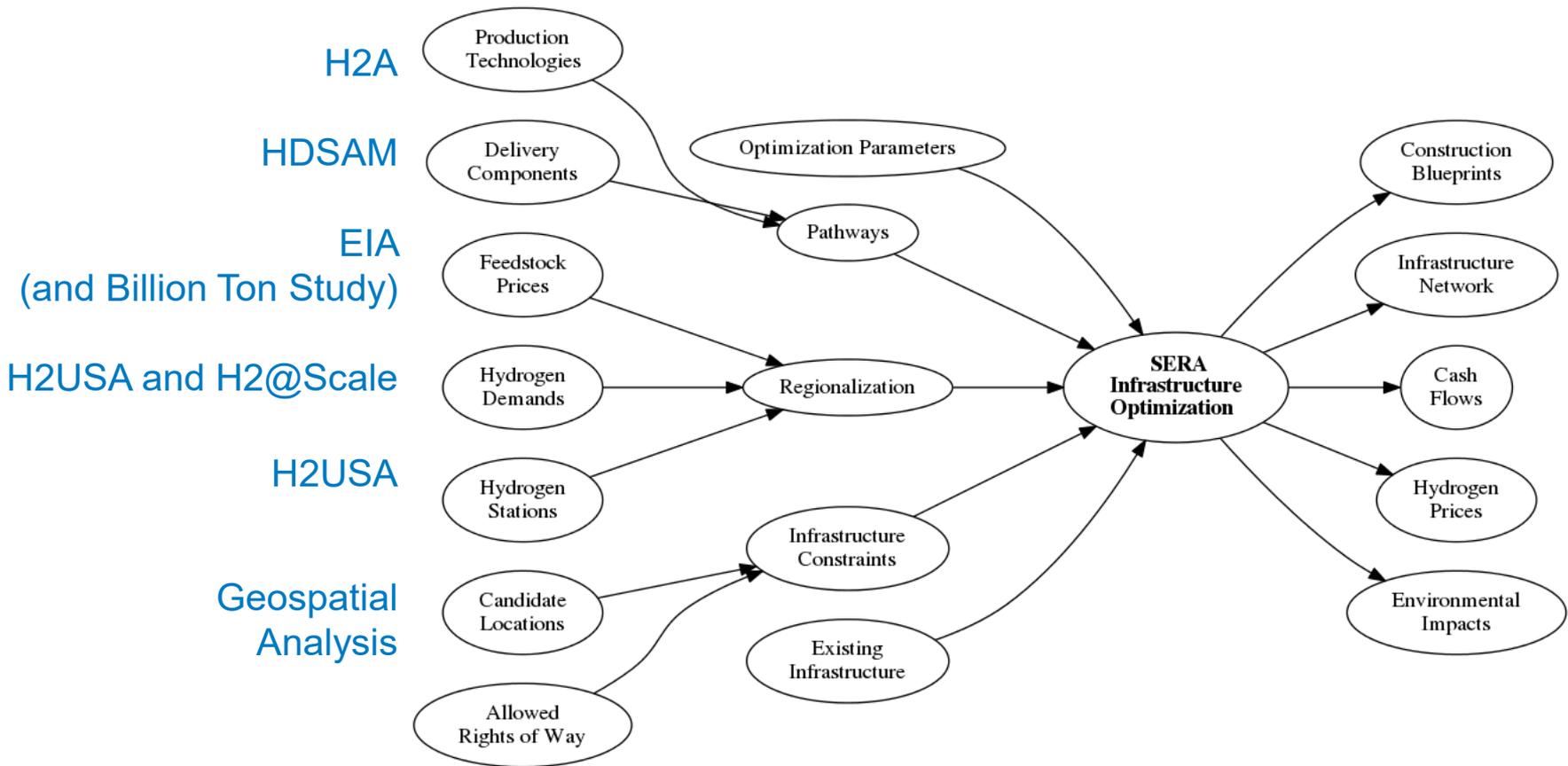
# Technical Back-Up Slides

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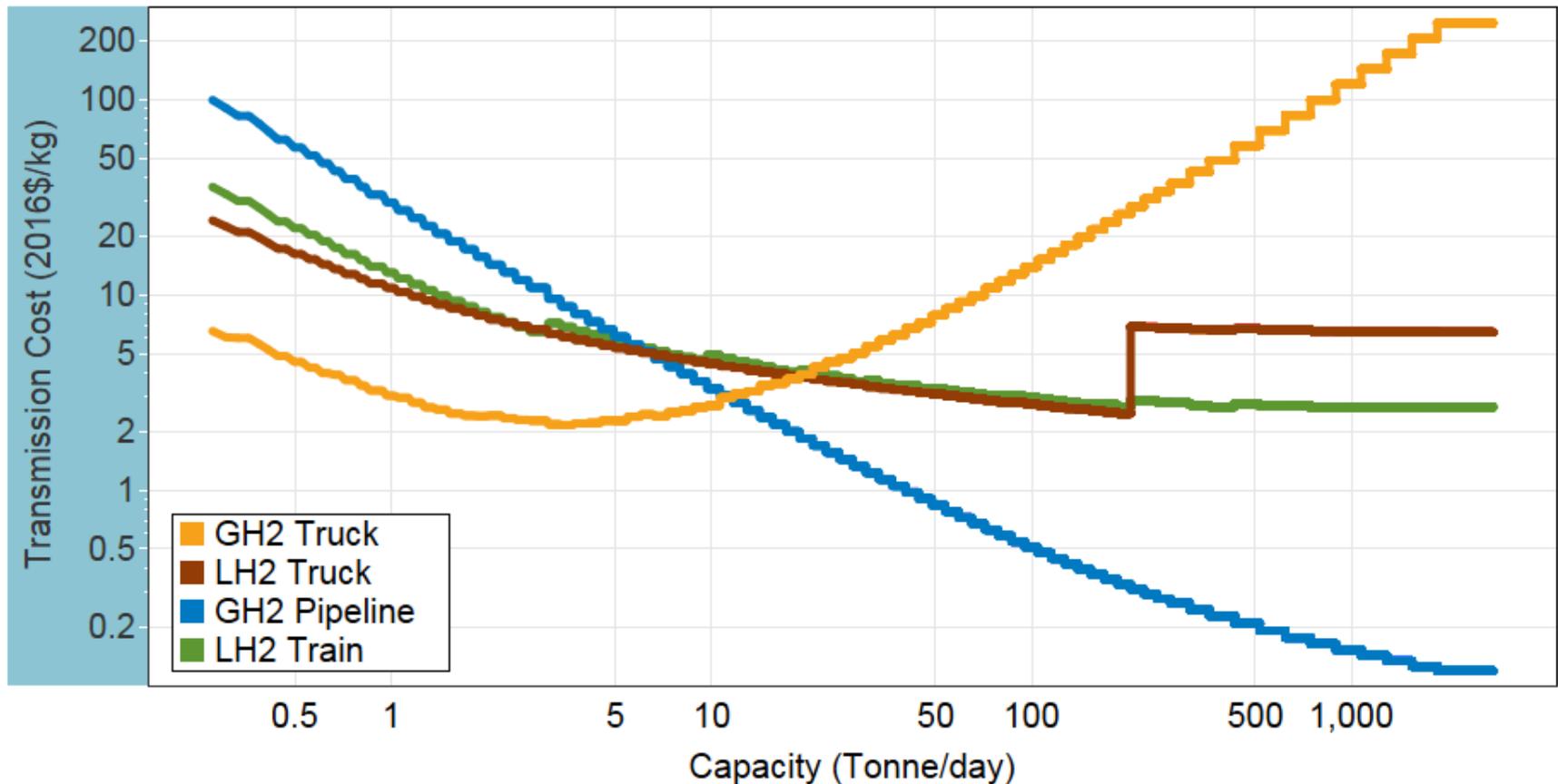
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# SERA Model Computational Data Flow

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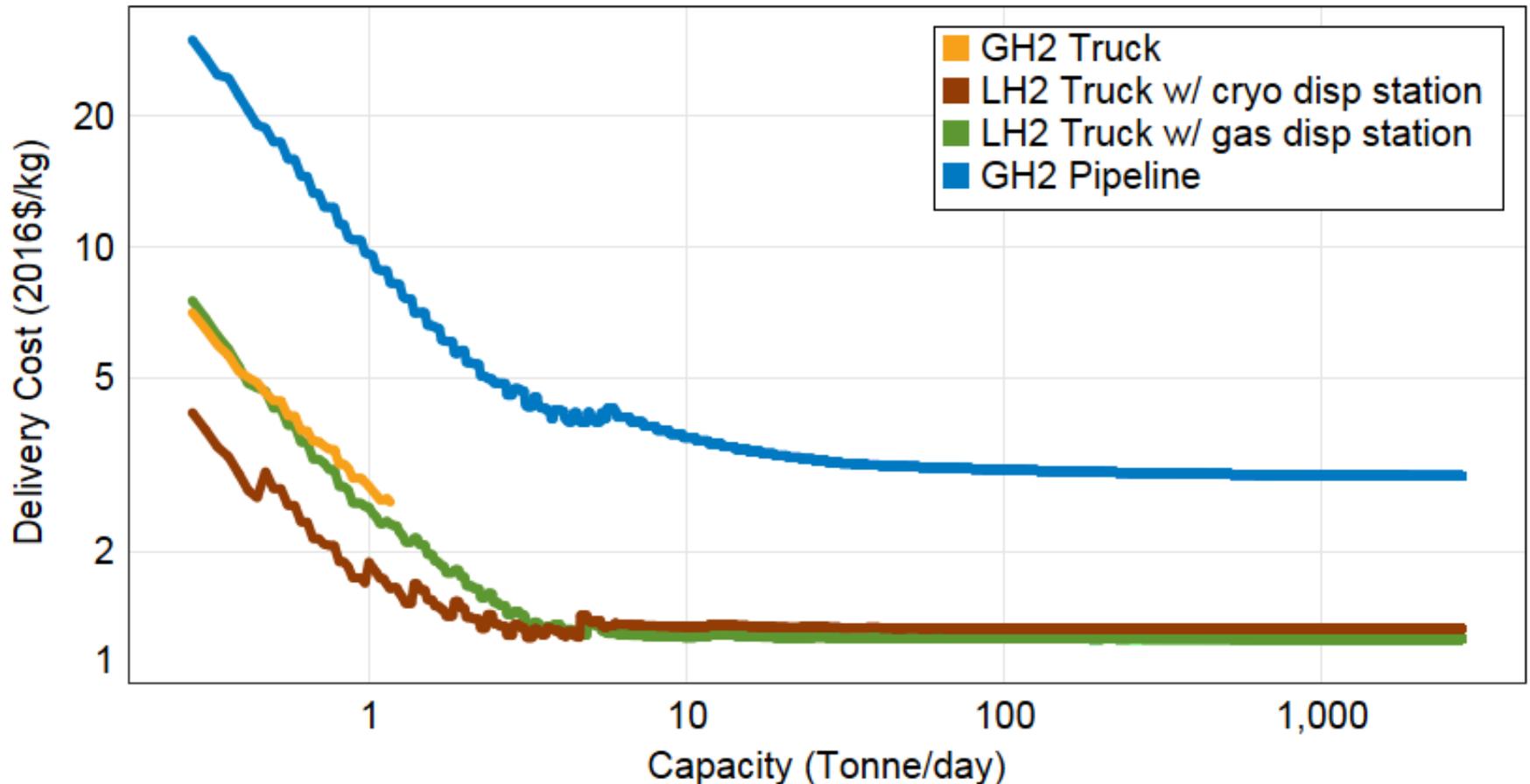


# Transmission Pathway Comparison



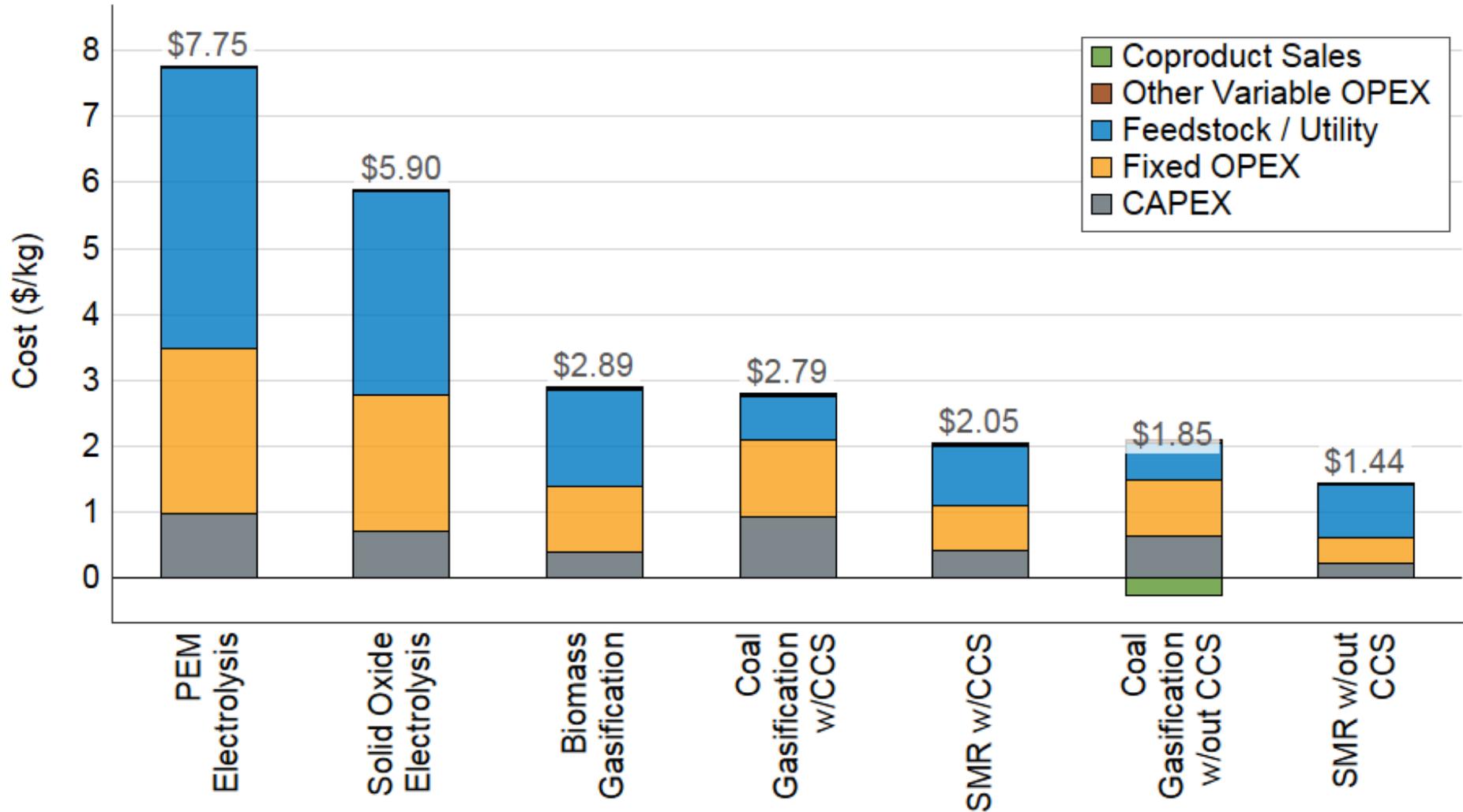
Transmission costs of the primary component technologies in the SERA model assuming a transmission distance of 100km. Truck delivery is well suited to small capacities and pipeline for high capacity transmission.

# Intra-City Distribution Pathway Comparison (no-terminal, or forecourt considerations)

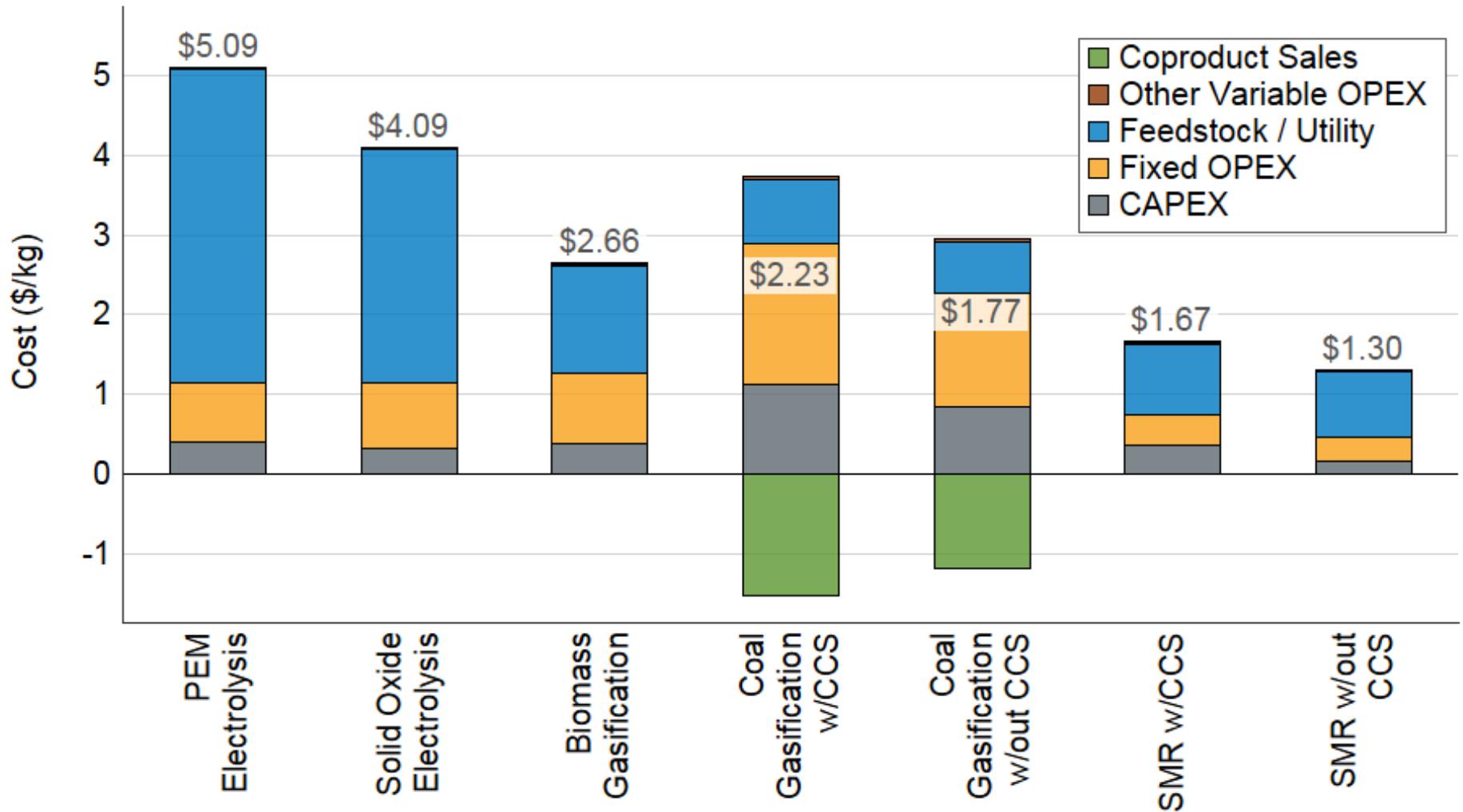


**Delivery costs (\$/kg) as a function of capacity for each delivery technology and refueling station type assuming a 5 km delivery distance (transmission costs not included)  
Within conventional pathways above, LH2 distribution outcompetes other modes.**

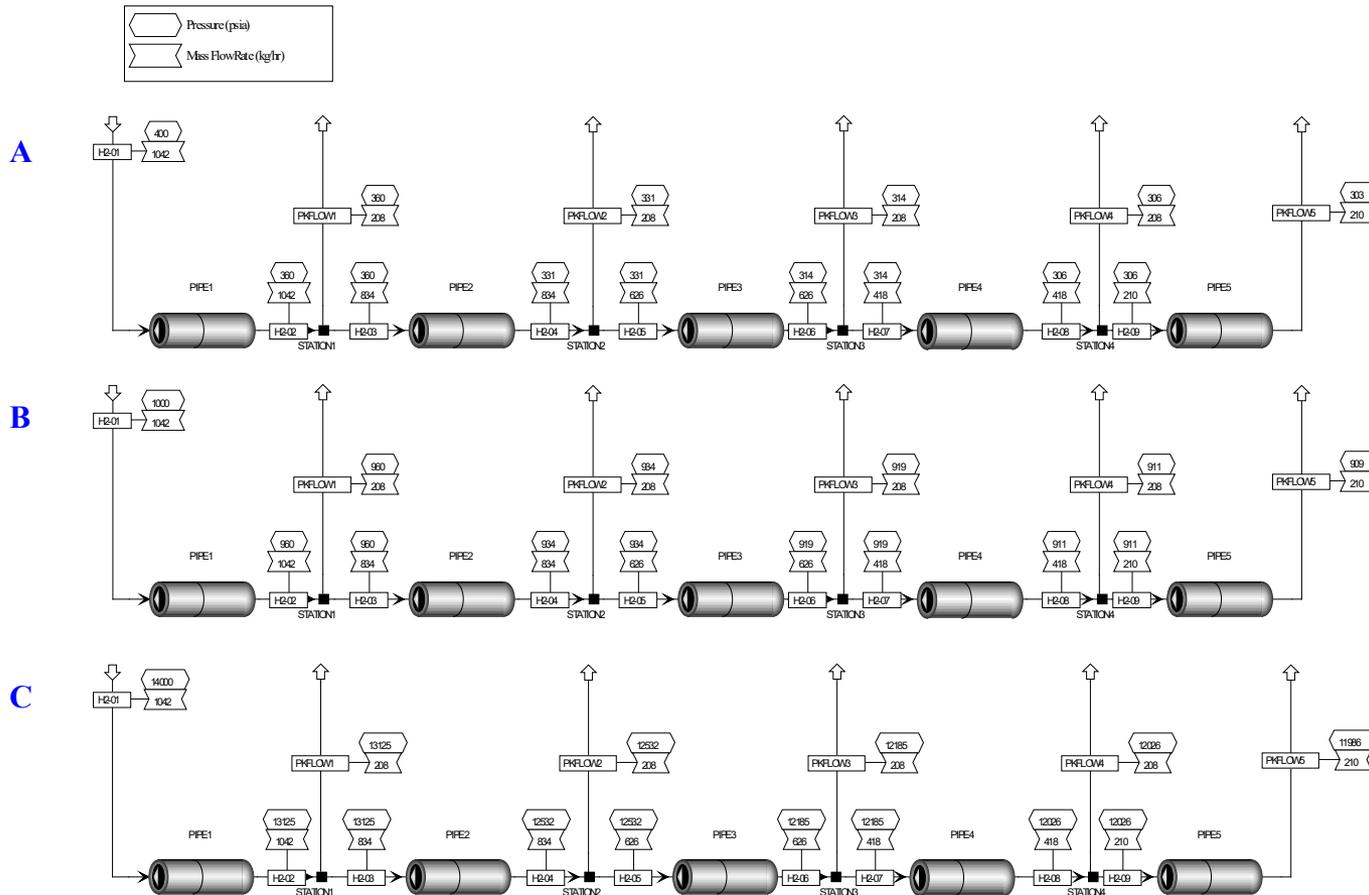
# H2A Cost Basis by Central H2 Production (Current Tech. Basis)



# H2A Cost Basis by Central H2 Production (Future Tech. Basis)

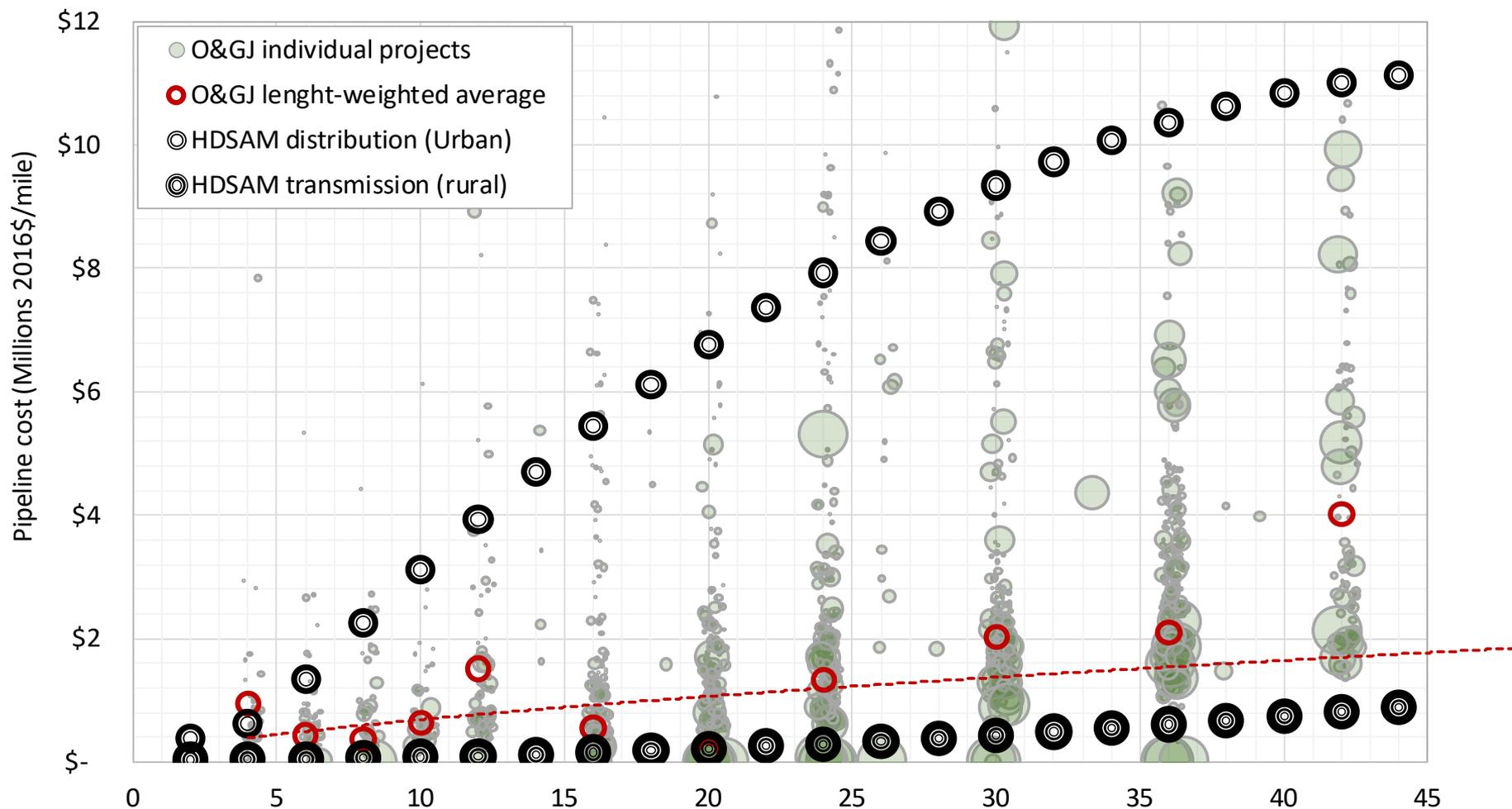


# Pipeline Sizing for Hydrogen Grid



**ASPEN modeling of hydrogen pipeline sizing for: (A) 400 psi pipeline inlet pressure (flow is from left to right), (B) 1,000 psi pipeline inlet, and (C) 14,000 psi pipeline inlet. Pipeline inner diameter corresponding with A, B, C scenarios is 3.6 in, 3.0 in, and 1.0 in, respectively.**

# Pipeline Cost Sources (Oil & Gas Journal, HDSAM)



**Price floor for pipeline cost of \$2M/mile was used based on industry feedback in context of high density urban settings.**

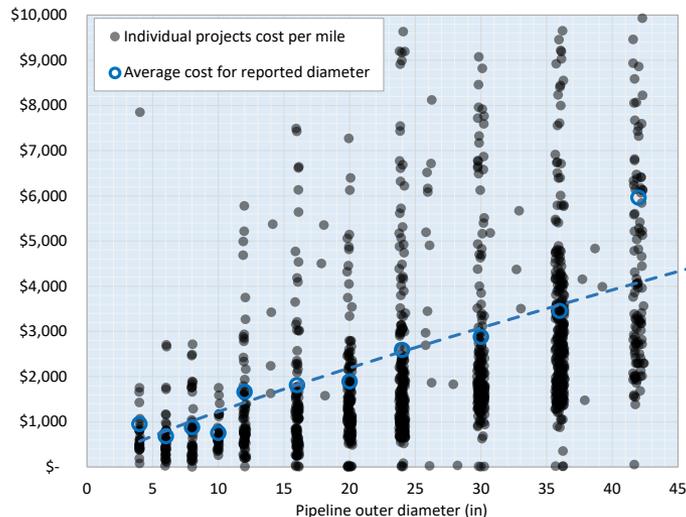
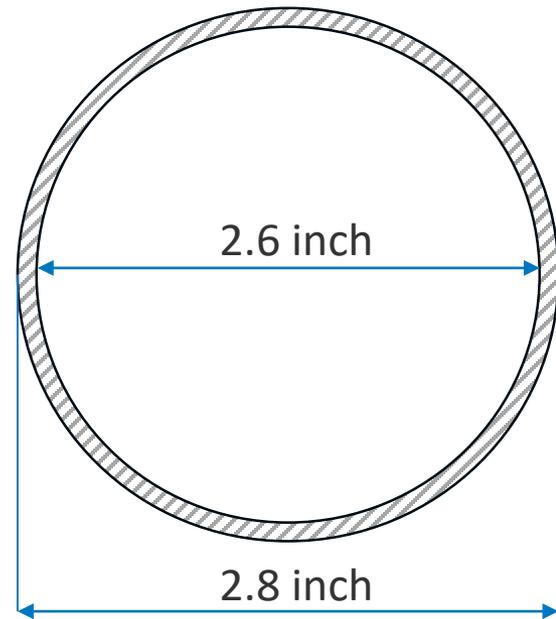
# Semi-Central techno-economics benchmark

## Pipe diameter scoping parameters:

- 25,000 kg/day flow capacity
- 2 mile length
- Inlet pressure 400 psig
- Pressure drop 100 psig
- Steel: A106 grade B (35,000 psi yield strength)

## Estimates:

- pipe inner diameter = 2.6 in
- wall thickness = 0.1 in (3x safety factor)
- H<sub>2</sub> stored in 2 mile pipe = 30 kg
- Pipeline material weight 2 miles = 18,000 lb



1321 pipeline projects  
1991 through 2016  
Reported in Oil & Gas Journal  
Examples use 6in pipe = \$800K/mile

## Take away:

Anticipated requirement: 900 psi, 3"OD  
Adopt conservative cost estimate of \$800K/mile  
for 6" OD pipe

# Centralized Dispensing-Level Compression

## Pipe diameter scoping parameters:

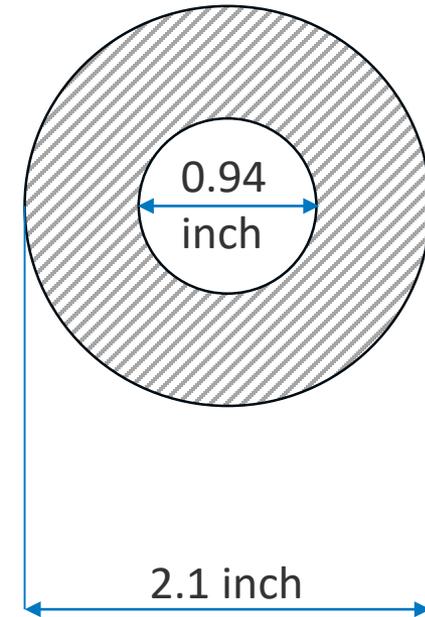
- 25,000 kg/day flow capacity
- 2 mile length
- Inlet pressure 13,750 psig
- Delivery pressure 12,000 psig
- Steel: A106 grade B (35,000 psi yield strength)

## Estimates:

- pipe inner diameter = 0.94 in
- wall thickness = 0.55 in (3x safety factor)
- H<sub>2</sub> stored in 2 mile pipe = 70 kg
- Pipeline material weight 2 miles = 93,000 lb

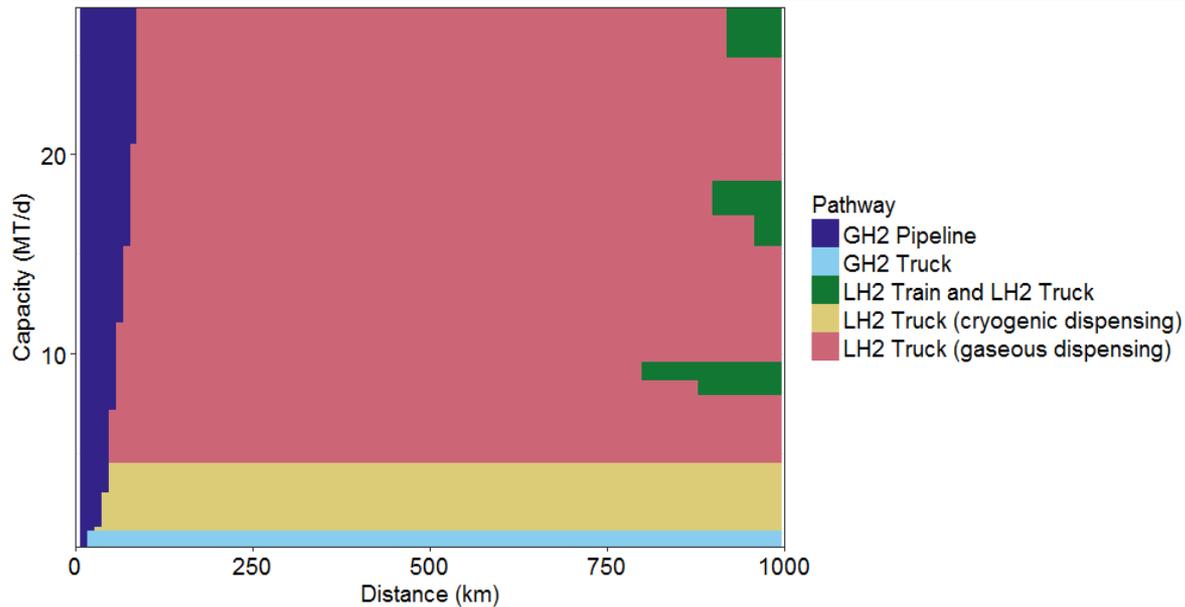
## Other benefits:

- economies of scale for compressor
  - central compressor is much cheaper than many smaller compressors
  - improved compressor oversight and reliability
- greatly improved back-to-back fill capability
- retail footprint minimized (can site on small urban retail sites)
  - no on-site storage
  - no storage set-back distances
  - no compressor
  - no maintenance access setbacks



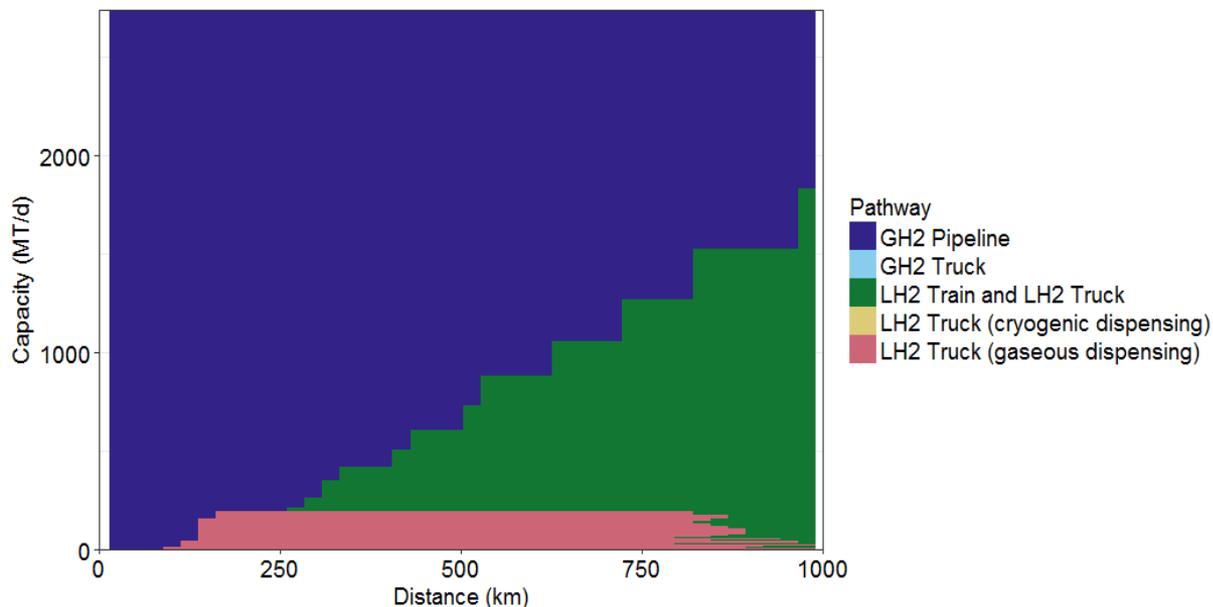
**Take away:** Centralizing compression can provide significant performance, siting, and economic benefits.

# Hydrogen Grid Distribution Pathway

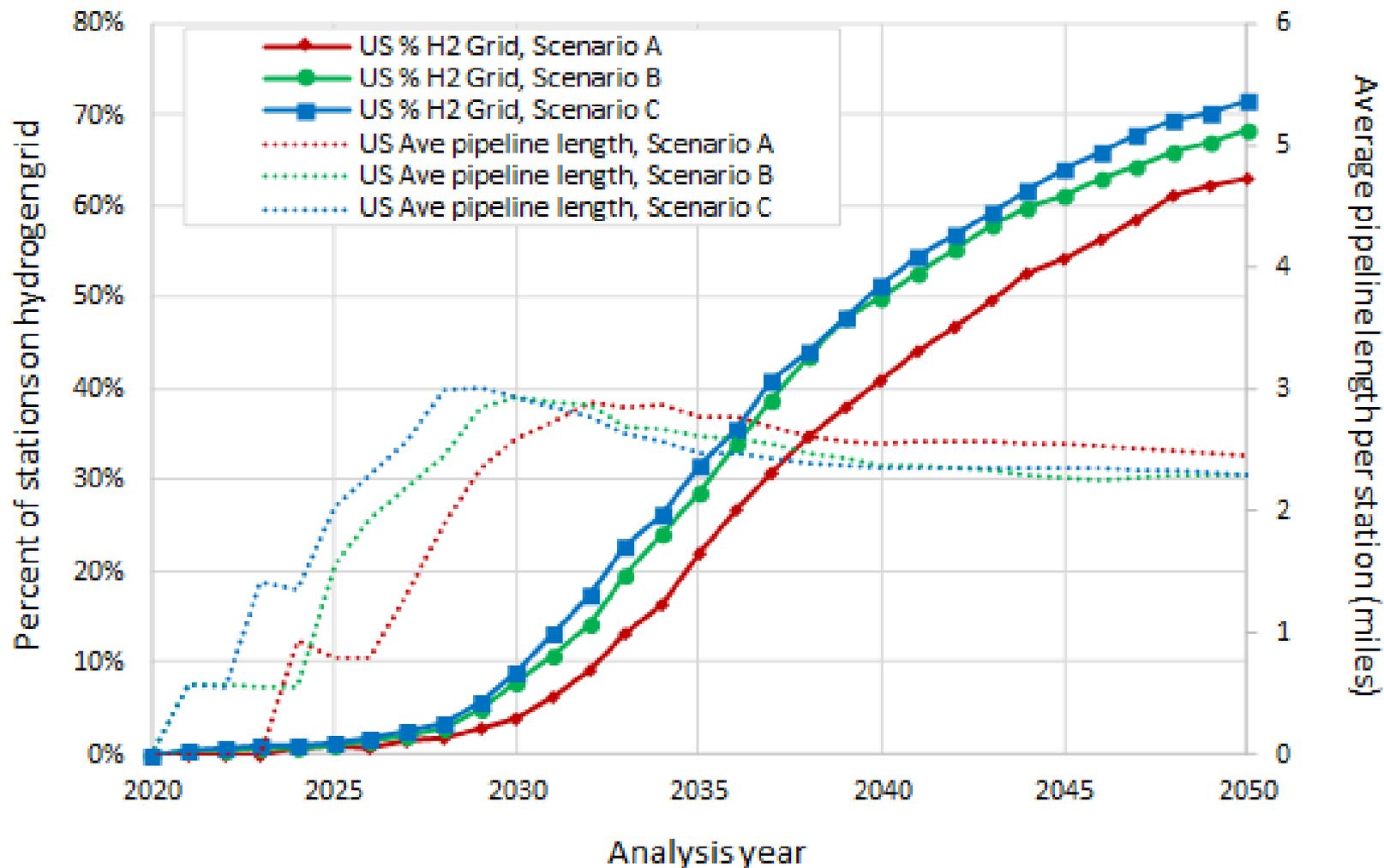


**Contour plot of lowest cost pathways for relatively low capacity (top) and high capacity (bottom) hydrogen supply-chain from the point of production to the retail station.**

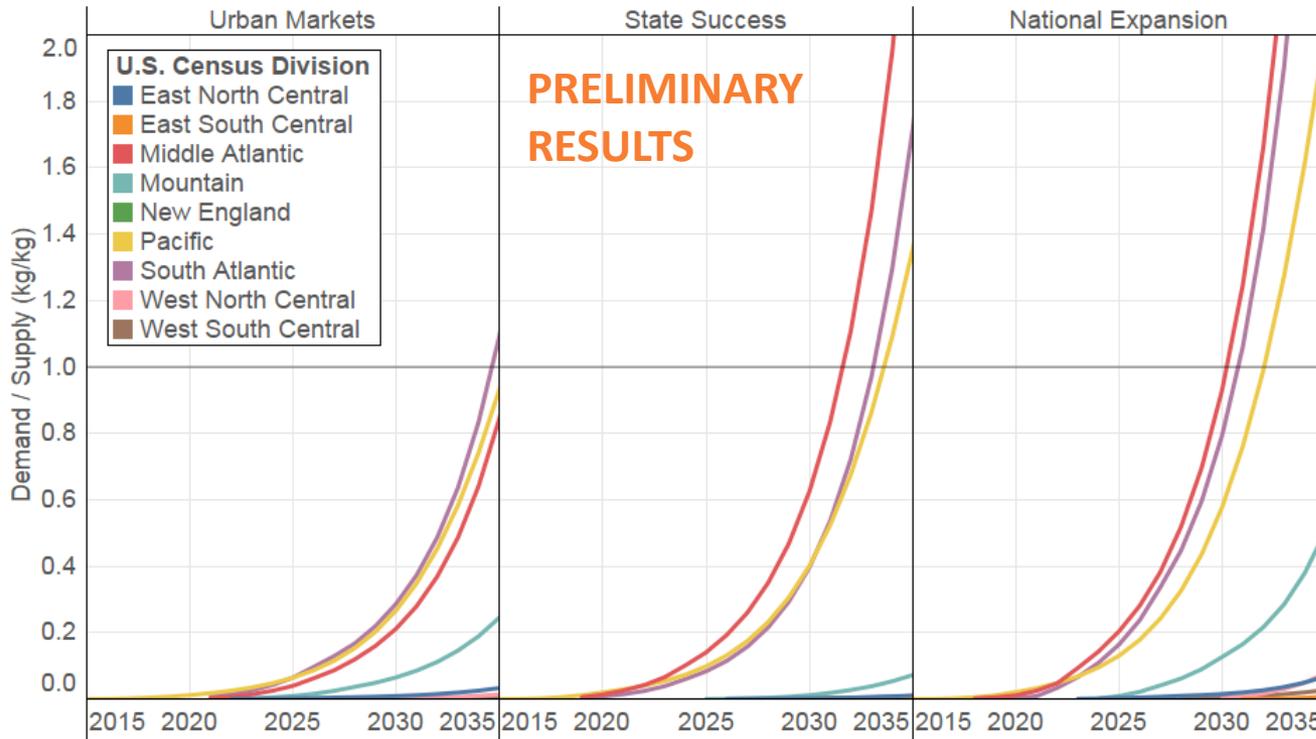
**Short intra-urban supply chains are dominated by pipeline delivery**



# H2 Grid Projection Nationally



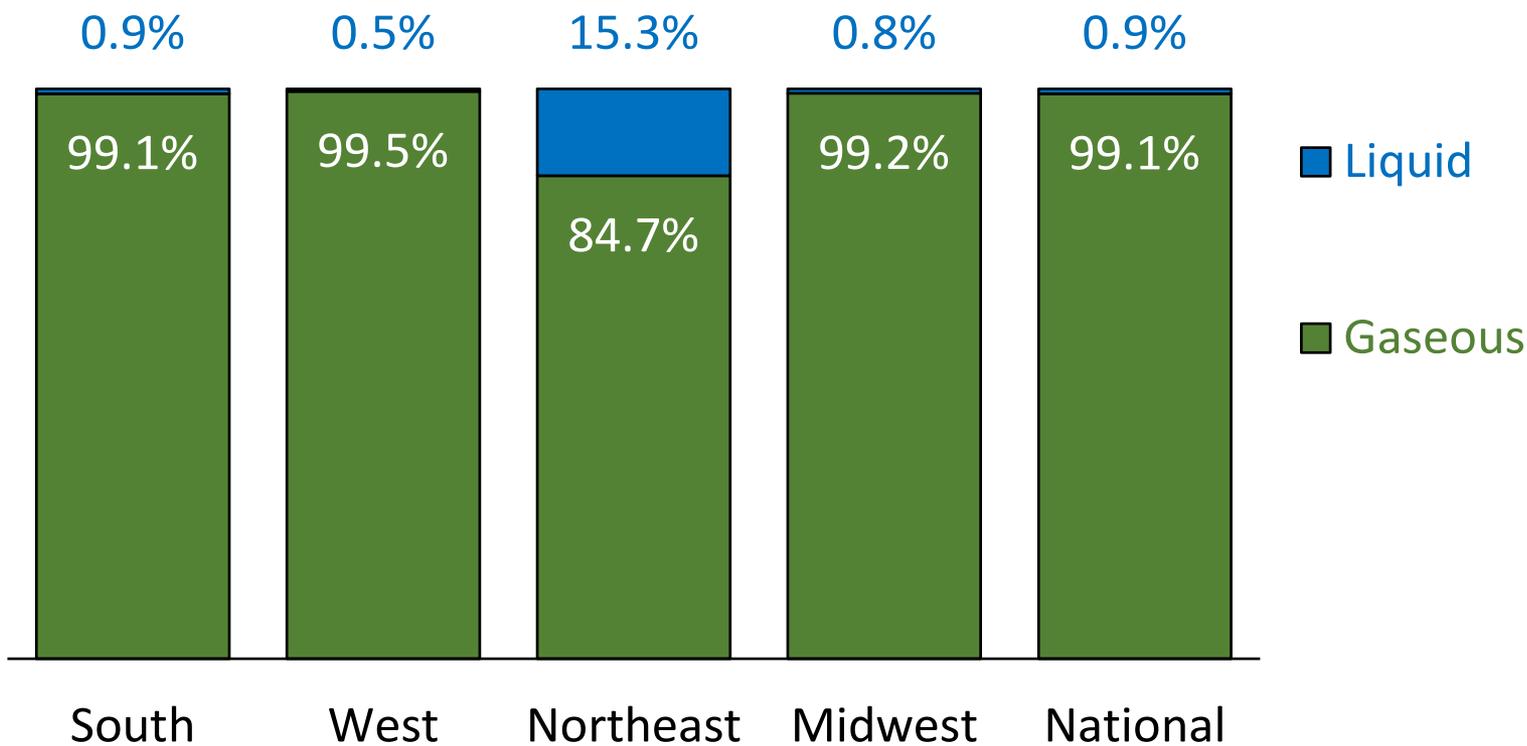
# LDV Hydrogen Demand Relative to Supply by Census Division



## Approximate order of stress on regional capacities:

- New England
- Middle Atlantic
- South Atlantic
- Pacific

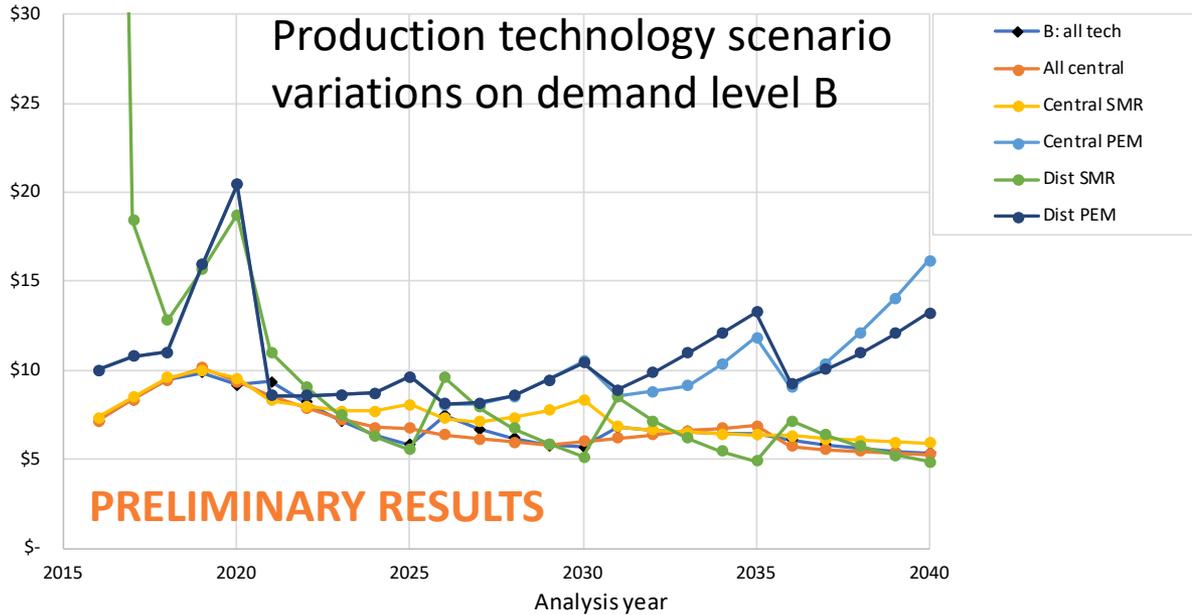
# Supply Constraints Relative to Product Phase Were Evaluated



**East Coast likely to see first stresses in regional supply. Liquid H<sub>2</sub> supply is limiting.**

# SERA Results: Hydrogen Profited Cost by Technology (diagnostic scenarios)

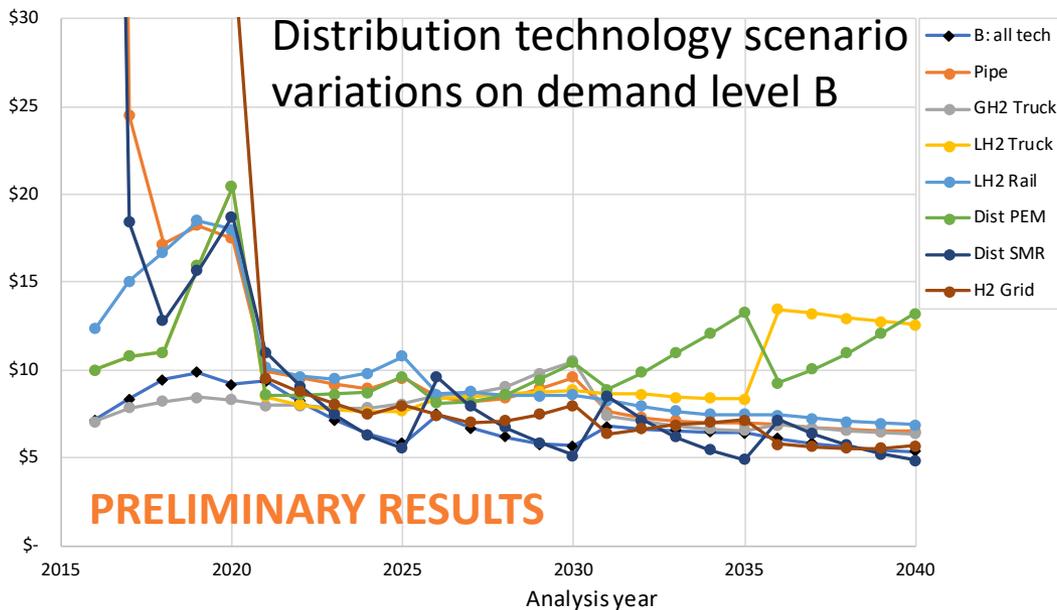
US non-levelized cost of H<sub>2</sub> / demand H<sub>2</sub> (\$/kg)



Scenarios reflect single pathways deployed through all the US. For example:

- All Central pathway allows model to build only central production.
- Central coal allows only coal pathway use for H<sub>2</sub> production
- All tech pathway allows all technologies to compete and yields lowest US market costs.

US non-levelized cost of H<sub>2</sub> / demand H<sub>2</sub> (\$/kg)



Note that single technology pathways individually yield higher cost than when utilizing technologies according to local conditions.

# Tabulated Hydrogen Profited Cost vs. Demand, Technology and Delivery Scenarios (diagnostic scenarios)

## PRELIMINARY RESULTS

Year	Demand scenario			Production scenario						Delivery scenario							
	A: all tech	B: all tech	C: all tech	B: all tech	All central	Central SMR	Central PEM	Dist SMR	Dist PEM	B: all tech	Pipe	GH2 Truck	LH2 Truck	LH2 Rail	Dist PEM	Dist SMR	H2 Grid
2016	\$58	\$7.16	>\$100	\$7.16	\$7.16	\$7.32	\$9.99	>\$100	\$9.99	\$7.16	>\$100	\$7.07	\$9.99	\$12.3	\$9.99	>\$100	>\$100
2017	\$13.1	\$8.36	\$18.0	\$8.36	\$8.36	\$8.48	\$10.8	\$18.4	\$10.8	\$8.36	\$24	\$7.84	\$10.8	\$15.1	\$10.8	\$18.4	\$38
2018	\$11.6	\$9.47	\$14.2	\$9.47	\$9.47	\$9.59	\$11.0	\$12.8	\$11.0	\$9.47	\$17.2	\$8.21	\$11.0	\$16.7	\$11.0	\$12.8	\$39
2019	\$11.0	\$9.84	\$9.91	\$9.84	\$10.1	\$10.0	\$15.9	\$15.6	\$15.9	\$9.84	\$18.2	\$8.45	\$15.9	\$18.5	\$15.9	\$15.6	\$39
2020	\$10.4	\$9.18	\$8.62	\$9.18	\$9.37	\$9.52	\$20	\$18.7	\$20	\$9.18	\$17.5	\$8.31	\$20	\$18.0	\$20	\$18.7	\$35
2021	\$10.3	\$9.35	\$9.25	\$9.35	\$8.56	\$8.30	\$8.57	\$11.0	\$8.57	\$9.35	\$9.97	\$7.99	\$8.51	\$10.1	\$8.57	\$11.0	\$9.54
2022	\$8.49	\$8.19	\$8.15	\$8.19	\$7.89	\$7.98	\$8.58	\$9.10	\$8.58	\$8.19	\$9.52	\$7.96	\$8.04	\$9.64	\$8.58	\$9.10	\$8.78
2023	\$7.38	\$7.15	\$7.16	\$7.15	\$7.24	\$7.69	\$8.61	\$7.48	\$8.61	\$7.15	\$9.15	\$7.86	\$7.77	\$9.51	\$8.61	\$7.48	\$8.09
2024	\$6.64	\$6.34	\$6.33	\$6.34	\$6.79	\$7.71	\$8.69	\$6.29	\$8.69	\$6.34	\$8.95	\$7.85	\$7.62	\$9.81	\$8.69	\$6.29	\$7.48
2025	\$6.12	\$5.83	\$5.88	\$5.83	\$6.76	\$8.07	\$9.63	\$5.54	\$9.63	\$5.83	\$9.54	\$8.05	\$7.65	\$10.8	\$9.63	\$5.54	\$7.99
2026	\$7.66	\$7.46	\$7.58	\$7.46	\$6.38	\$7.29	\$8.06	\$9.58	\$8.14	\$7.46	\$8.47	\$8.51	\$8.34	\$8.61	\$8.14	\$9.58	\$7.45
2027	\$6.79	\$6.71	\$6.80	\$6.71	\$6.13	\$7.13	\$8.08	\$7.93	\$8.14	\$6.71	\$8.19	\$8.65	\$8.49	\$8.78	\$8.14	\$7.93	\$6.99
2028	\$6.62	\$6.17	\$6.28	\$6.17	\$5.97	\$7.34	\$8.53	\$6.76	\$8.57	\$6.17	\$8.41	\$9.03	\$8.62	\$8.58	\$8.57	\$6.76	\$7.08
2029	\$6.53	\$5.77	\$6.10	\$5.77	\$5.83	\$7.75	\$9.46	\$5.85	\$9.45	\$5.77	\$8.97	\$9.81	\$8.75	\$8.53	\$9.45	\$5.85	\$7.46
2030	\$6.44	\$5.67	\$6.04	\$5.67	\$6.02	\$8.33	\$10.5	\$5.14	\$10.4	\$5.67	\$9.60	\$10.5	\$8.85	\$8.60	\$10.4	\$5.14	\$7.98
2031	\$6.56	\$6.77	\$6.68	\$6.77	\$6.17	\$6.81	\$8.56	\$8.47	\$8.90	\$6.77	\$7.60	\$7.40	\$8.63	\$8.28	\$8.90	\$8.47	\$6.38
2032	\$6.25	\$6.65	\$6.43	\$6.65	\$6.39	\$6.66	\$8.80	\$7.17	\$9.87	\$6.65	\$7.30	\$7.09	\$8.63	\$7.94	\$9.87	\$7.17	\$6.64
2033	\$6.20	\$6.56	\$6.31	\$6.56	\$6.59	\$6.53	\$9.12	\$6.19	\$10.9	\$6.56	\$7.09	\$6.84	\$8.45	\$7.66	\$10.9	\$6.19	\$6.86
2034	\$6.14	\$6.47	\$6.26	\$6.47	\$6.73	\$6.43	\$10.3	\$5.46	\$12.1	\$6.47	\$7.00	\$6.66	\$8.37	\$7.50	\$12.1	\$5.46	\$7.03
2035	\$6.07	\$6.41	\$6.21	\$6.41	\$6.89	\$6.37	\$11.8	\$4.92	\$13.3	\$6.41	\$6.95	\$6.55	\$8.34	\$7.45	\$13.3	\$4.92	\$7.15
2036	\$6.09	\$6.08	\$6.01	\$6.08	\$5.71	\$6.31	\$9.05	\$7.17	\$9.27	\$6.08	\$6.86	\$6.89	\$13.5	\$7.44	\$9.27	\$7.17	\$5.79
2037	\$5.83	\$5.81	\$5.76	\$5.81	\$5.55	\$6.16	\$10.4	\$6.35	\$10.1	\$5.81	\$6.70	\$6.71	\$13.2	\$7.22	\$10.1	\$6.35	\$5.64
2038	\$5.67	\$5.59	\$5.56	\$5.59	\$5.43	\$6.05	\$12.1	\$5.72	\$11.0	\$5.59	\$6.59	\$6.57	\$13.0	\$7.06	\$11.0	\$5.72	\$5.56
2039	\$5.56	\$5.45	\$5.39	\$5.45	\$5.35	\$5.97	\$14.1	\$5.22	\$12.1	\$5.45	\$6.52	\$6.46	\$12.8	\$6.95	\$12.1	\$5.22	\$5.56
2040	\$5.46	\$5.36	\$5.25	\$5.36	\$5.29	\$5.90	\$16.1	\$4.83	\$13.2	\$5.36	\$6.49	\$6.37	\$12.6	\$6.87	\$13.2	\$4.83	\$5.67

Note: Distributed SMR shows small advantage in some years, as emerging low-density come online. This technology is however outcompeted by other pathways after an introductory period.